

A Multi-Model Analysis of Aerosol Effects on Clouds Simulated by Global Climate Models

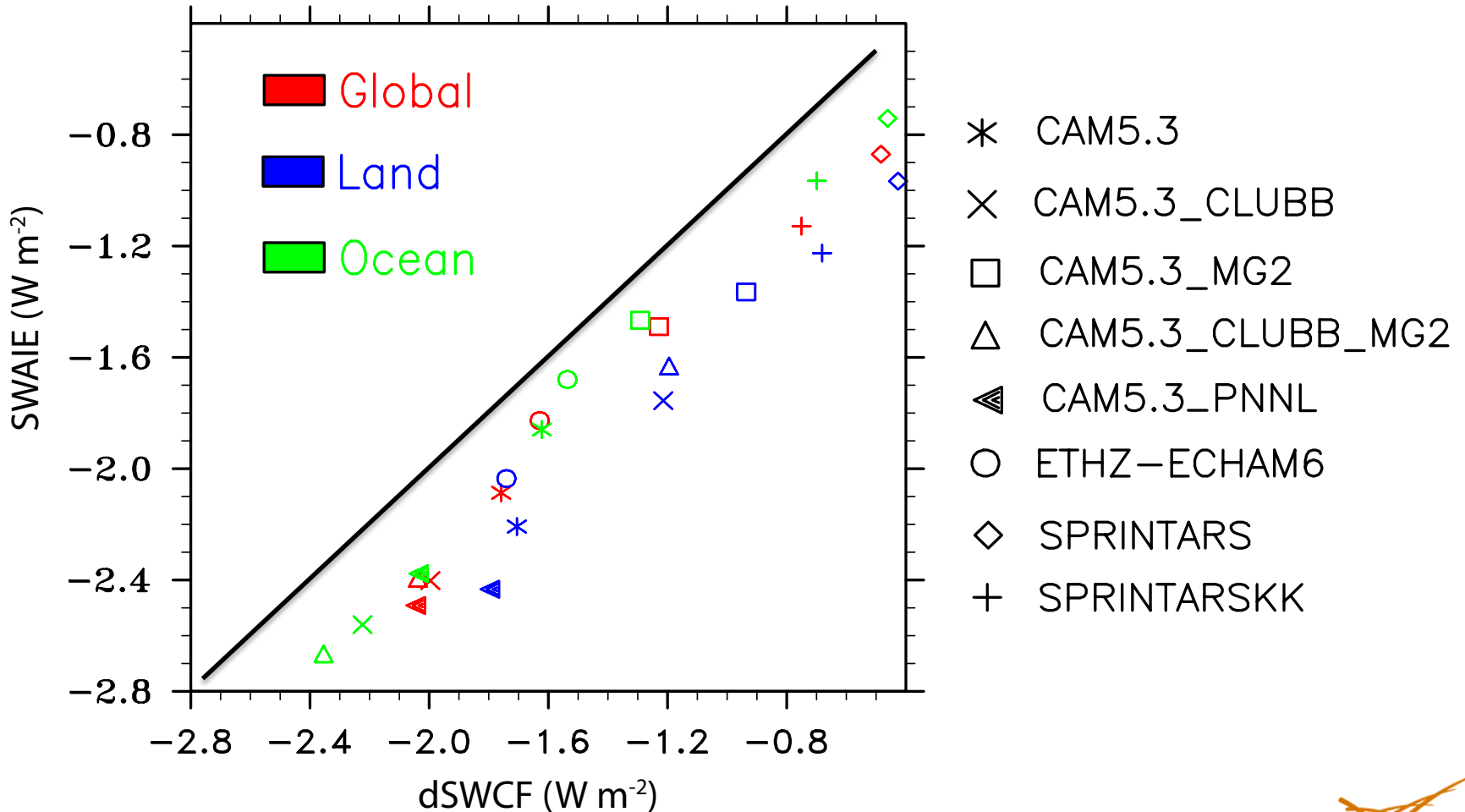
Steven Ghan, Minghuai Wang, H. Wang, and K. Zhang
Pacific Northwest National Laboratory

D. Neubauer, U. Lohmann, and S. Ferrachat
ETH

T. Takamura
Kyushu University

Andrew Gettelman, Hugh Morrison - NCAR

Aerosol shortwave indirect forcing (SWAIE)* vs change in shortwave cloud forcing (dSWCF)



*Ghan, *Atmos. Chem. Phys.* (2013)

Factorization

$$\Delta R = R \frac{d \ln R}{d \ln \tau} \frac{d \ln \tau}{d \ln N_d} \frac{d \ln N_d}{d \ln CCN} \frac{d \ln CCN}{d \ln E} \Delta \ln E$$

R : “clean-sky” shortwave cloud forcing

ΔR : aerosol indirect forcing, aka ERF_{aci}

τ : cloud optical depth N_d : cloud droplet number

CCN : CCN at 1 km (0.1% supersaturation)

E : anthropogenic emission

L : liquid water path r_e : droplet effective radius

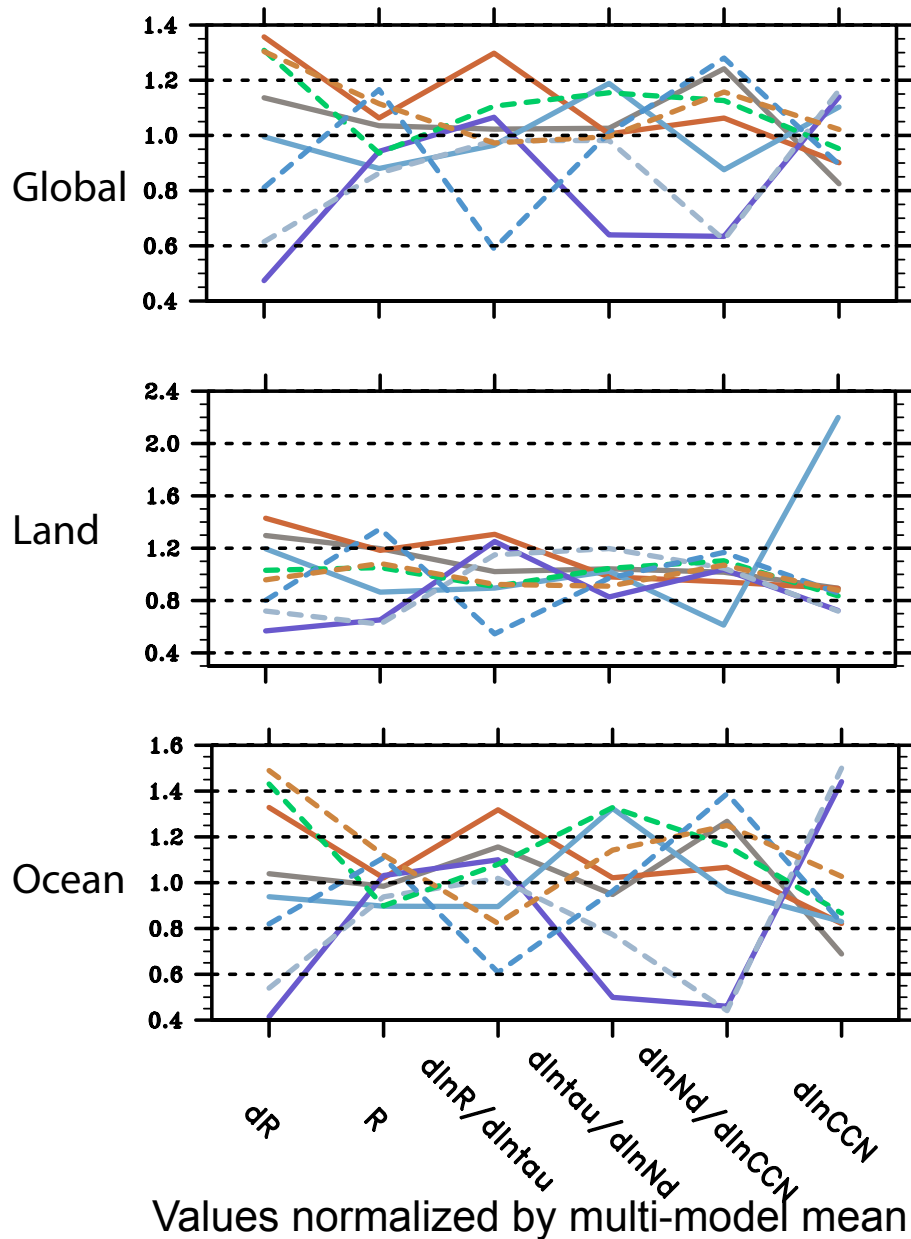
$$\frac{d \ln \tau}{d \ln N_d} = \frac{\partial \ln \tau}{\partial \ln r_e} \frac{d \ln r_e}{d \ln N_d} + \frac{\partial \ln \tau}{\partial \ln L} \frac{d \ln L}{d \ln N_d}$$

$$\simeq - \frac{d \ln r_e}{d \ln N_d} + \frac{d \ln L}{d \ln N_d} \quad \leftarrow \quad \tau \propto \frac{L}{r_e}$$

albedo
effect

lifetime
effect

Factorization



- CAM5.3_CLUBB_MG2
- CAM5.3_MG2
- CAM5.3_CLUBB
- SPRINTARSKK
- SPRINTARS
- ECHAM6
- CAM5.3_PNNL
- CAM5.3

dR: ERFaci

R: “clean-sky” shortwave cloud forcing

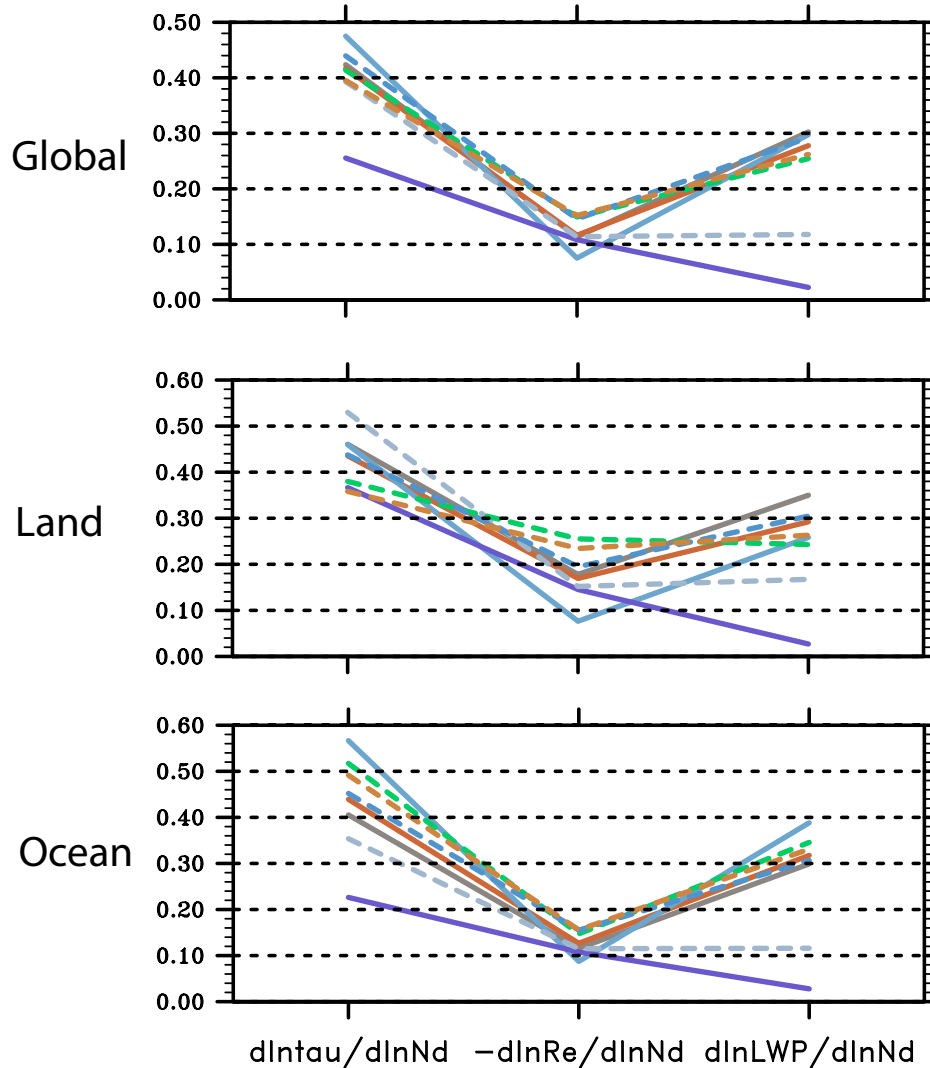
tau: cloud optical depth

Nd: cloud droplet number

CCN: CCN concentration

$$\Delta R = R \frac{d \ln R}{d \ln \tau} \frac{d \ln \tau}{d \ln N_d} \frac{d \ln N_d}{d \ln CCN} \Delta \ln CCN$$

Decomposition: $d\ln\tau/d\ln N_d$



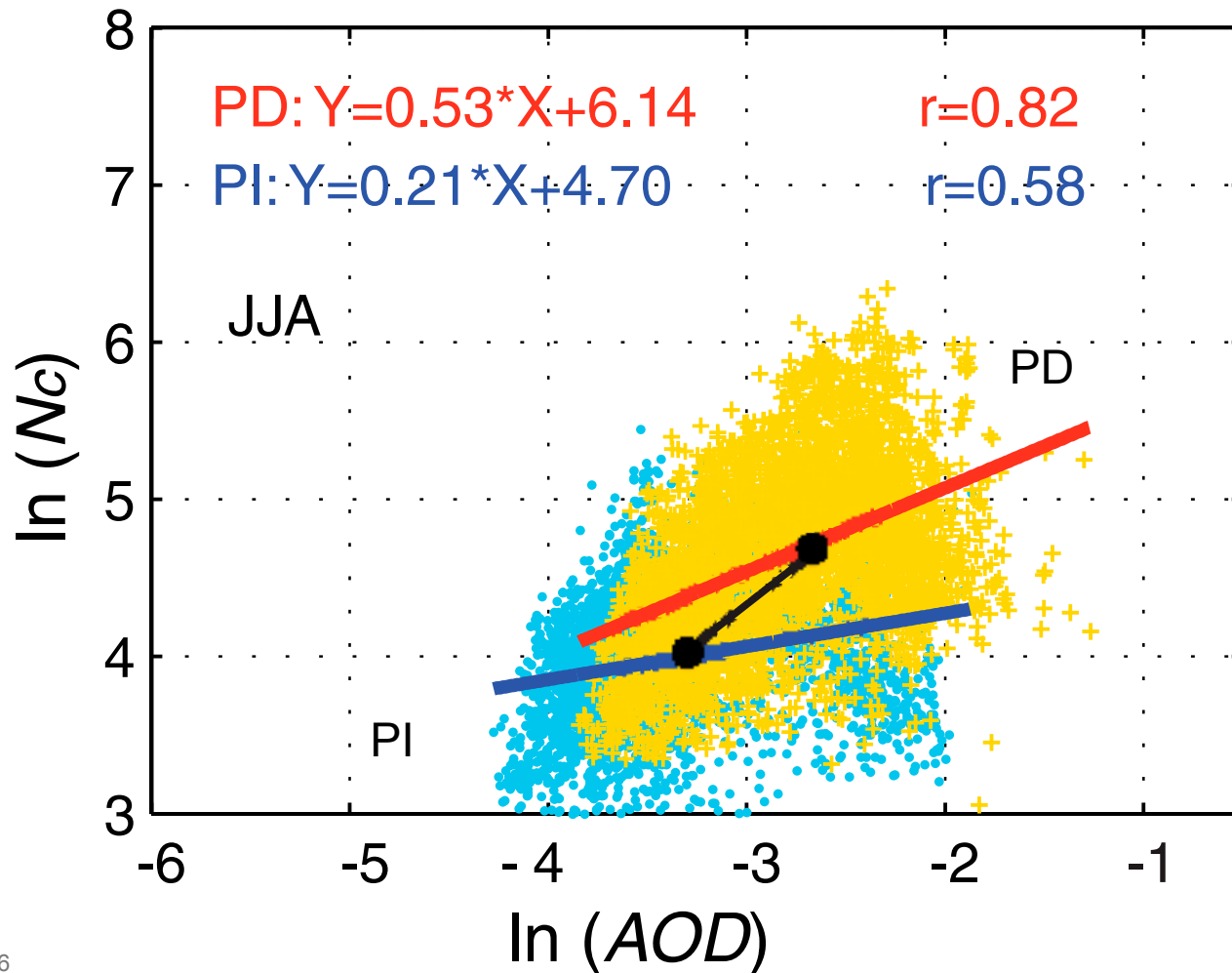
- CAM5.3_CLUBB_MG2
- CAM5.3_MG2
- CAM5.3_CLUBB
- SPRINTARSKK
- SPRINTARS
- ECHAM6
- CAM5.3_PNNL
- CAM5.3

tau: cloud optical depth
 Nd: cloud droplet number
 CCN: CCN concentration
 LWP: liquid water path

$$\frac{d\ln\tau}{d\ln N_d} = \frac{\partial\ln\tau}{\partial\ln r_e} \frac{d\ln r_e}{d\ln N_d} + \frac{\partial\ln\tau}{\partial\ln L} \frac{d\ln L}{d\ln N_d}$$

Values NOT normalized by multi-model mean

Constraints from present day variability might not apply to pre-industrial to present day changes

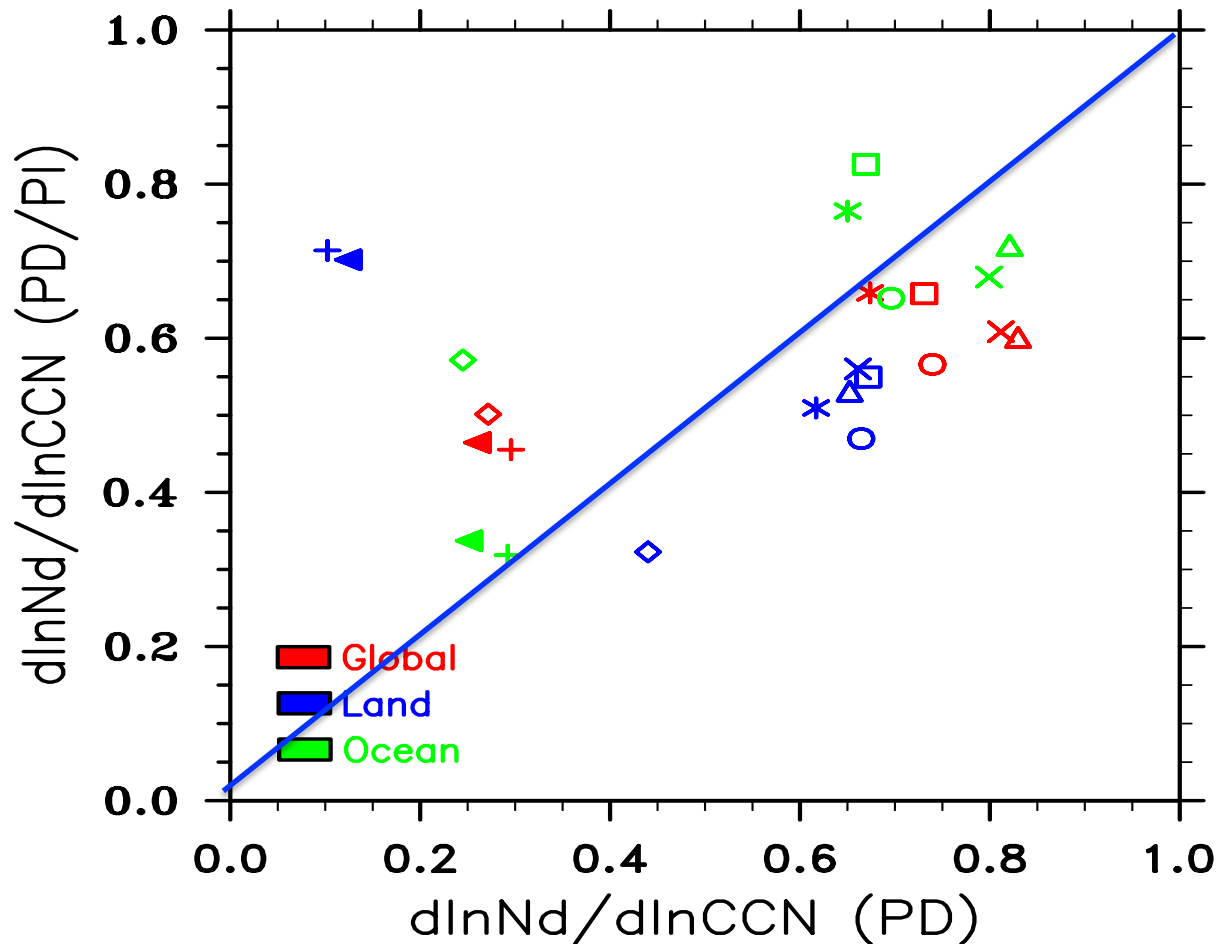


Penner et al., PNAS (2011)



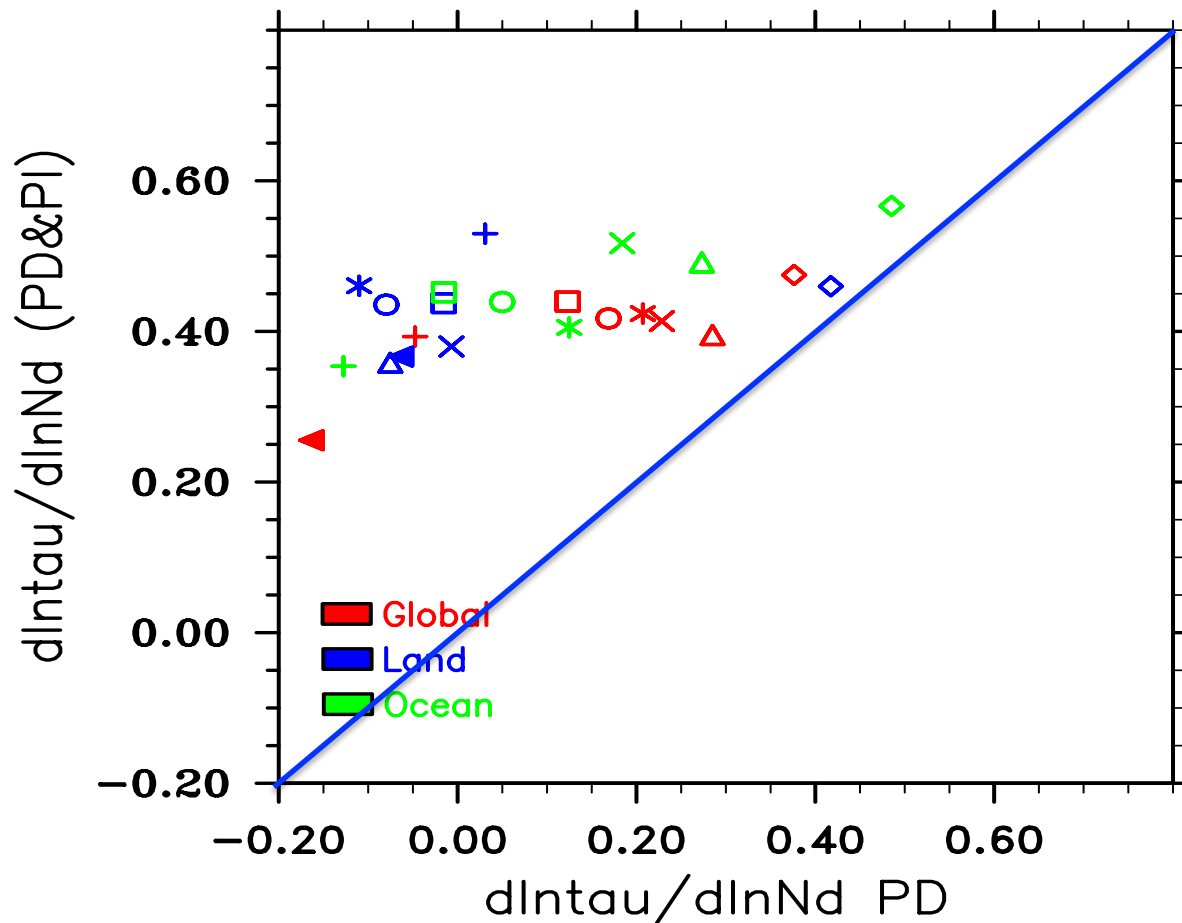
Pacific Northwest
NATIONAL LABORATORY

$d\ln Nd/d\ln CCN$ (PD) vs. $d\ln Nd/d\ln CCN$ (PD-PI)



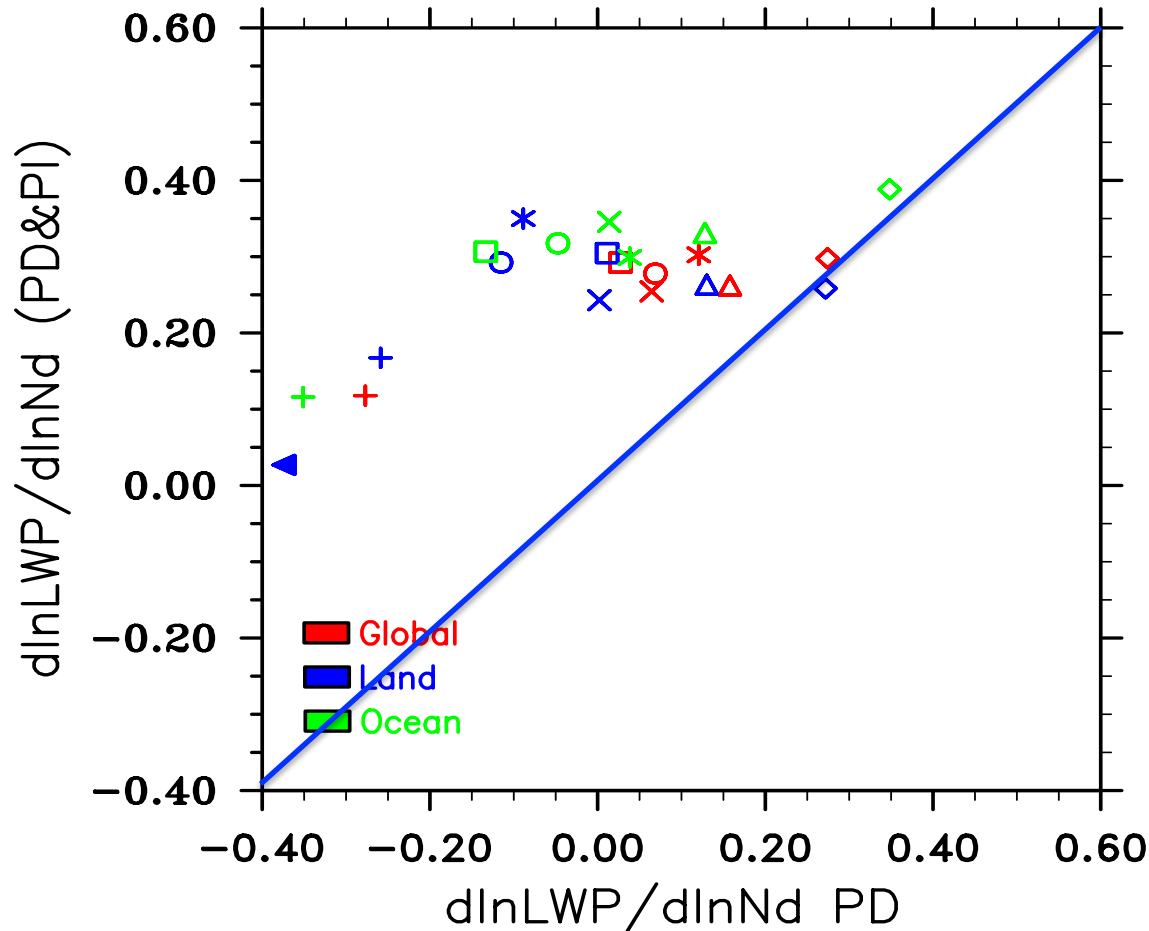
* CAM5.3 x CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2
◄ CAM5.3_PNNL ○ ETHZ-ECHAM6 ◇ SPRINTARS + SPRINTARSKK

dIntau/dlnNd (PD) vs. dIntau/dlnNd (PD&PI)



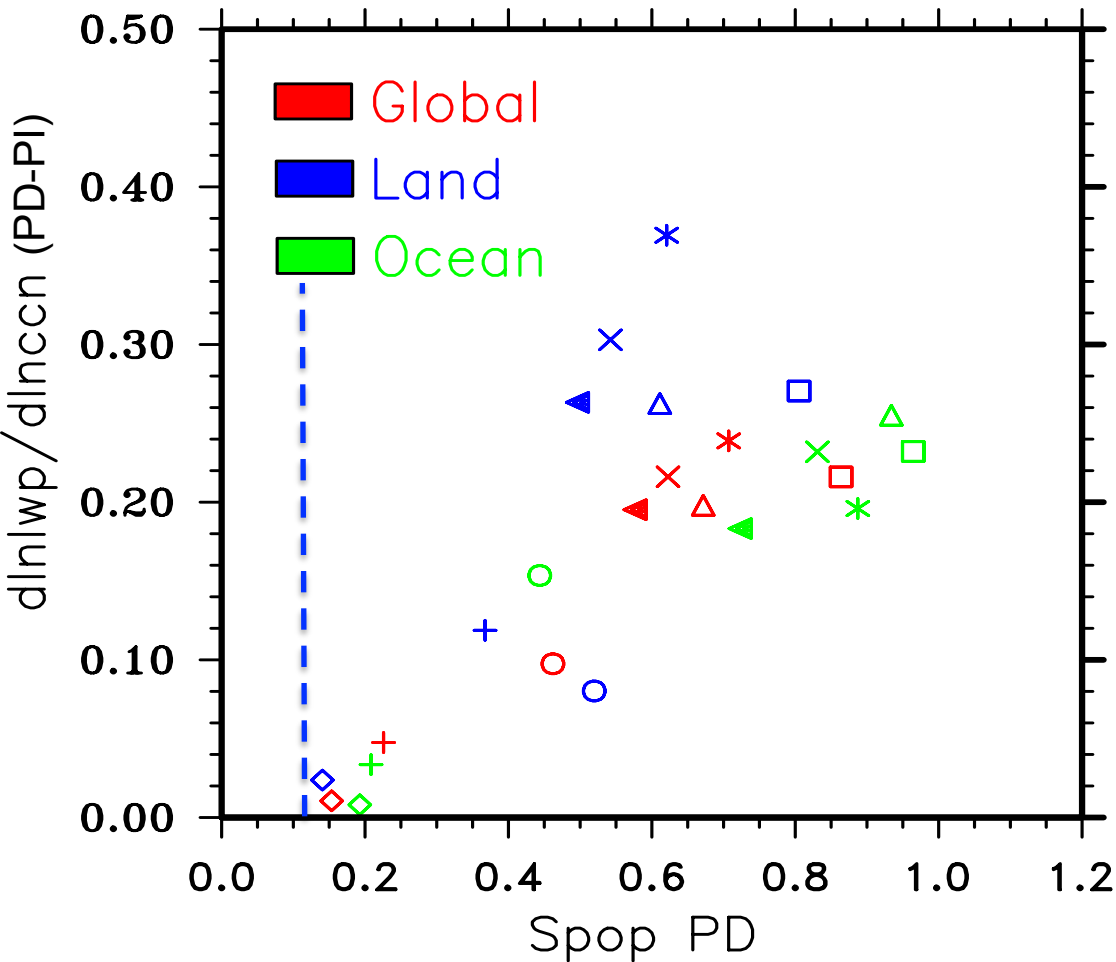
* CAM5.3 x CAM5.3_CLUBB □ CAM5.3_MG2 Δ CAM5.3_CLUBB_MG2
◄ CAM5.3_PNNL ○ ETHZ-ECHAM6 ◇ SPRINTARS + SPRINTARS_SKK

$d\ln LWP/d\ln Nd$ (PD) vs. $d\ln LWP/d\ln Nd$ (PD-PI)

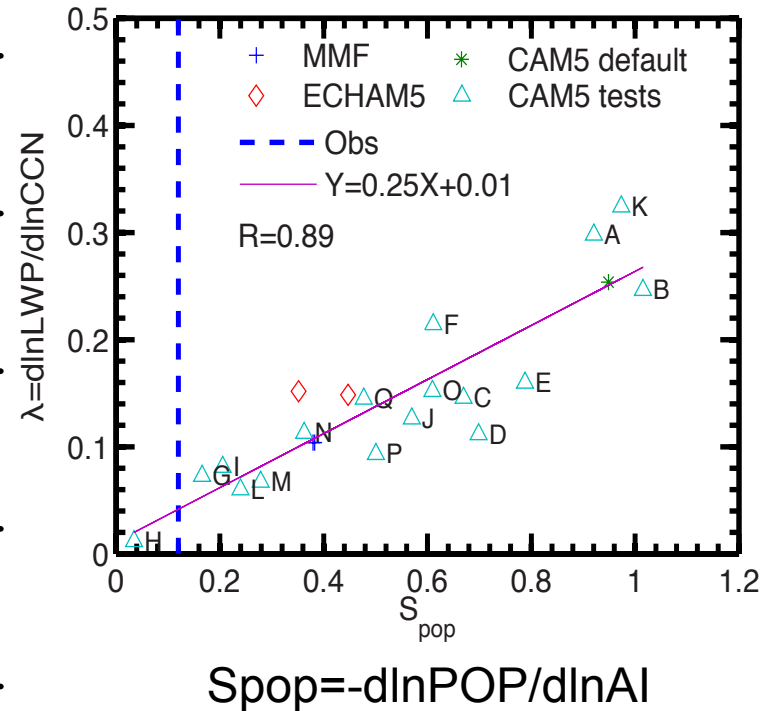


* CAM5.3 × CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2
▲ CAM5.3_PNNL ○ ETHZ-ECHAM6 ◇ SPRINTARS + SPRINTARSKK

Spop vs. dlnLWP/dlnCCN (PD-PI)



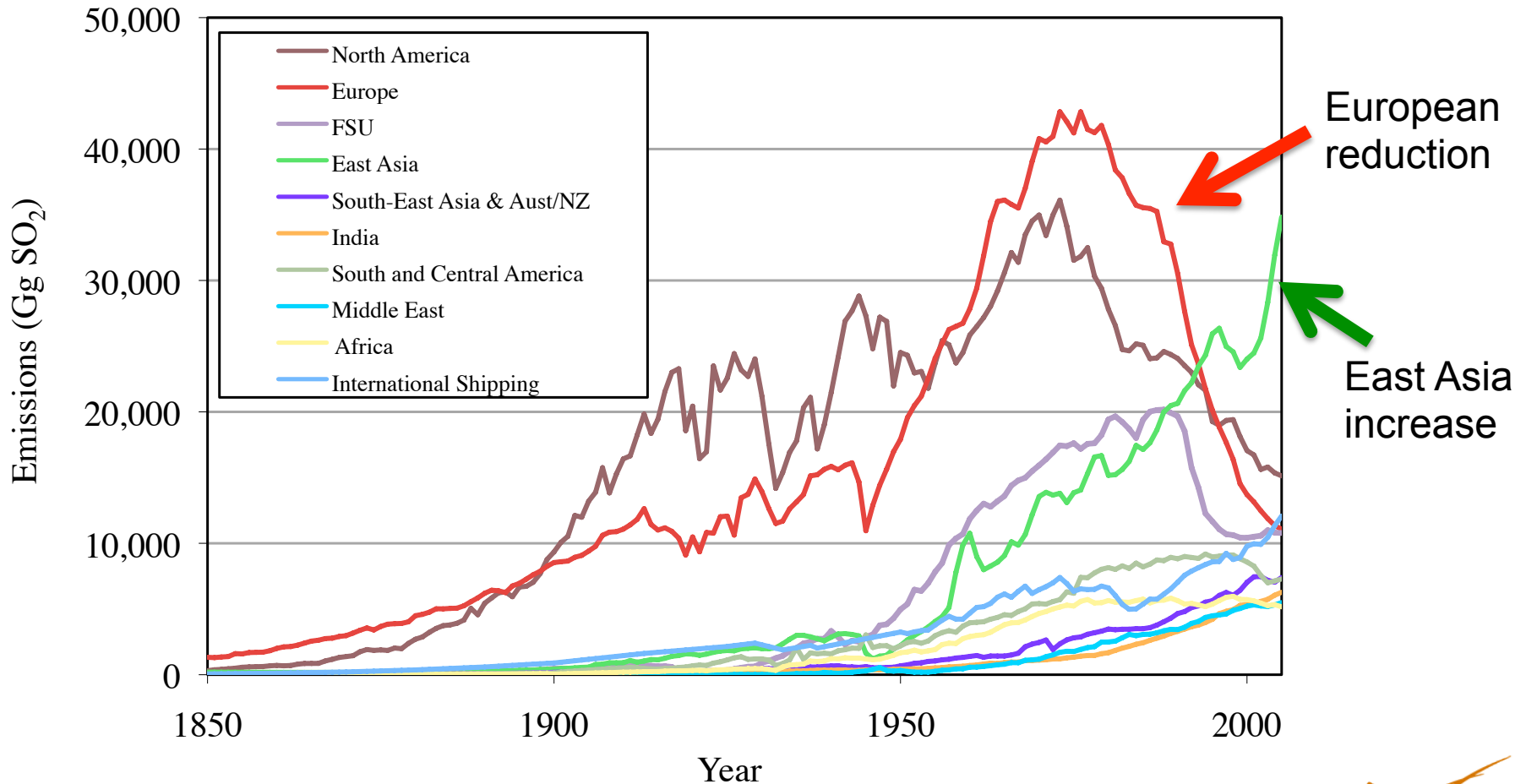
Over ocean
(Wang et al., 2012, GRL)



* CAM5.3 × CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2
◄ CAM5.3_PNNL ○ ETHZ-ECHAM6 ◇ SPRINTARS + SPRINTARSKK

Opportunities from Recent Regional Changes in Emissions

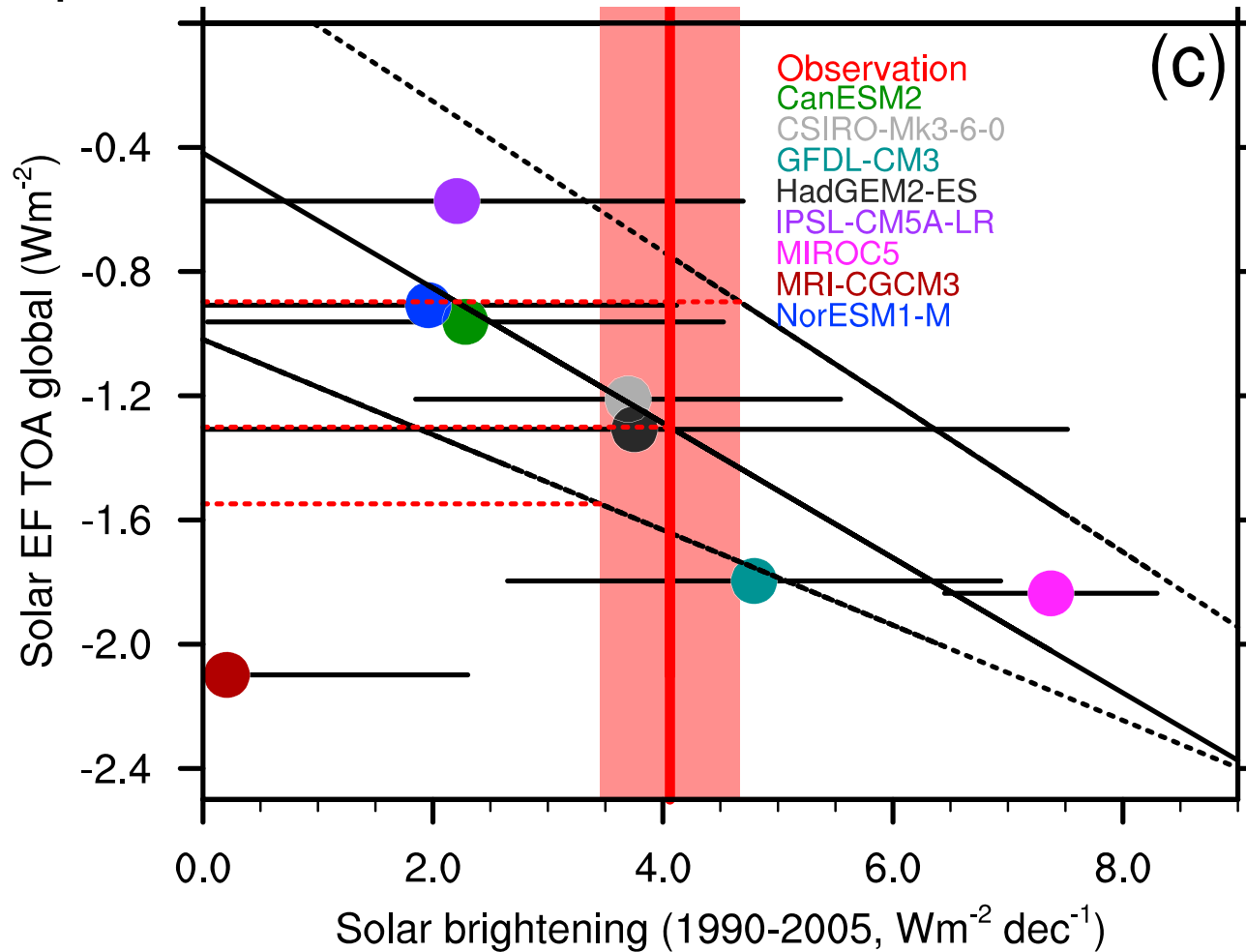
Global Anthropogenic SO₂ Emissions



Smith et al., ACP (2011)

Constraining Forcing with Recent Changes

- ▶ Satellite data not available to constrain factors during this period

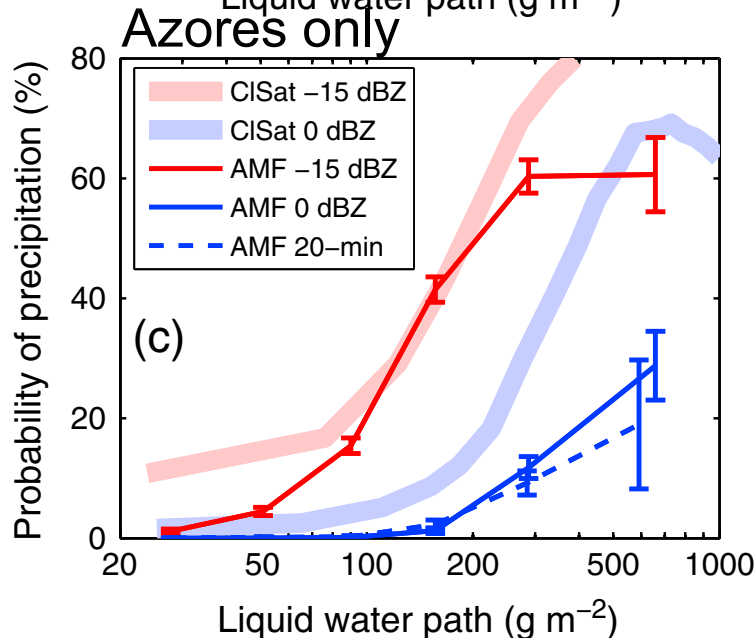
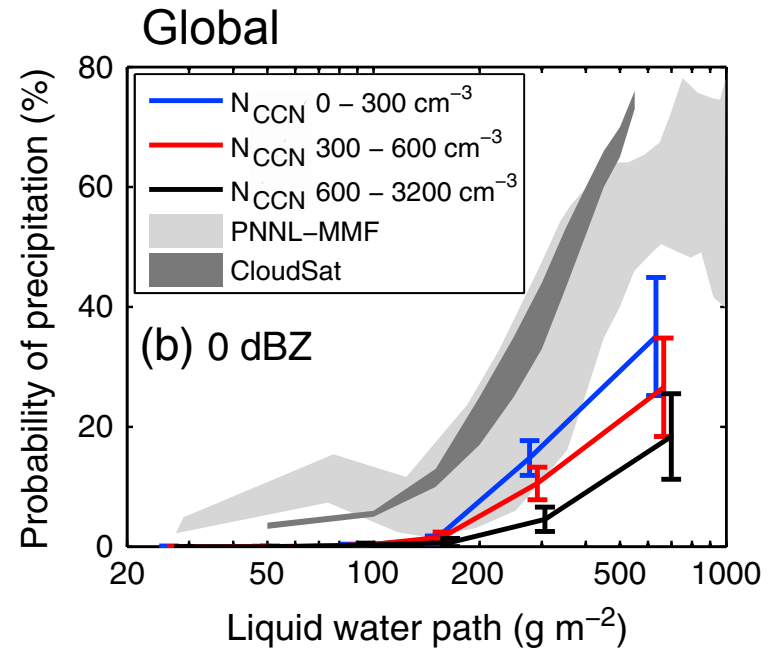
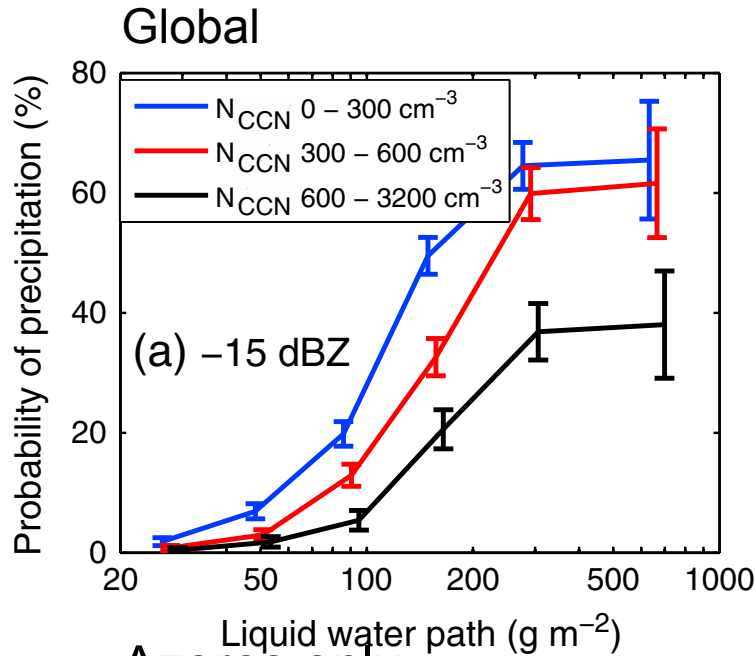


Conclusions

- ▶ Diversity in estimated effective radiative forcing through aerosol effects on clouds is driven by diversity in several factors, particularly
 - Sensitivity of droplet number to CCN
 - Sensitivity of liquid water path to droplet number
- ▶ Constraints on anthropogenic aerosol effects are needed
- ▶ Constraining sensitivities using data from present day variability not sufficient to constrain anthropogenic aerosol effects
- ▶ New present day metrics are needed to constrain anthropogenic aerosol effects
- ▶ Regional trends for selected periods could be helpful
- ▶ Global data availability limits trend analysis to post 2002

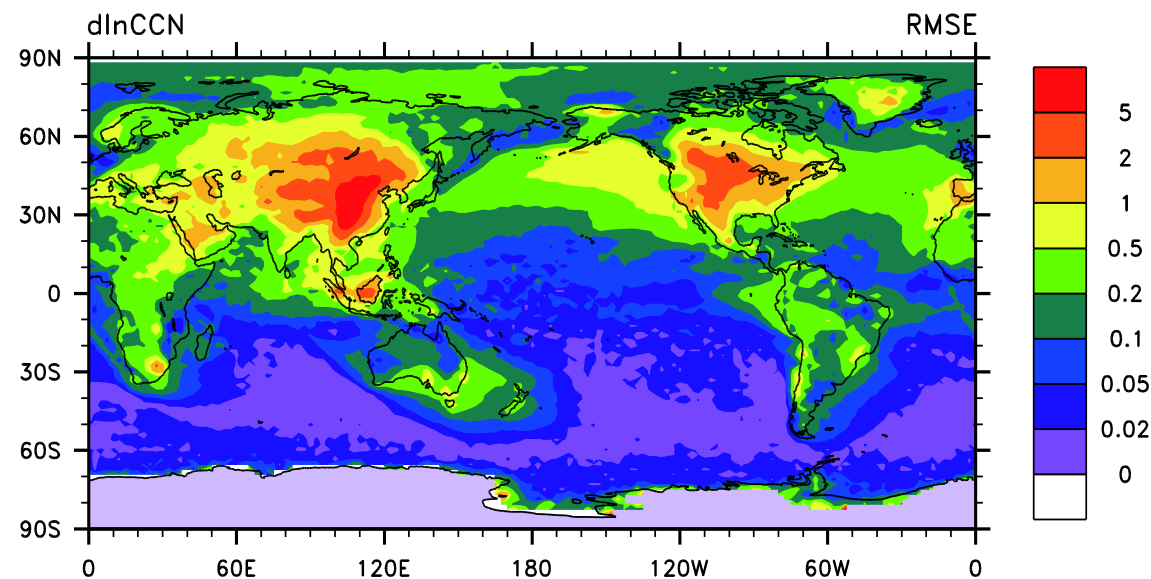
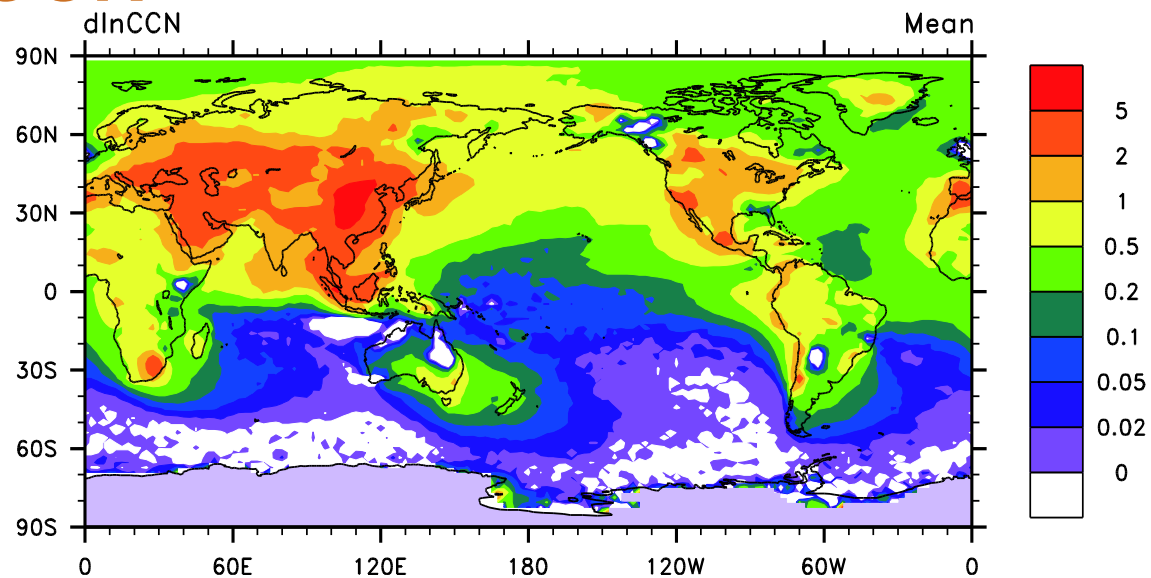
THANKS!

Satellite vs Surface-Based Remote Sensing

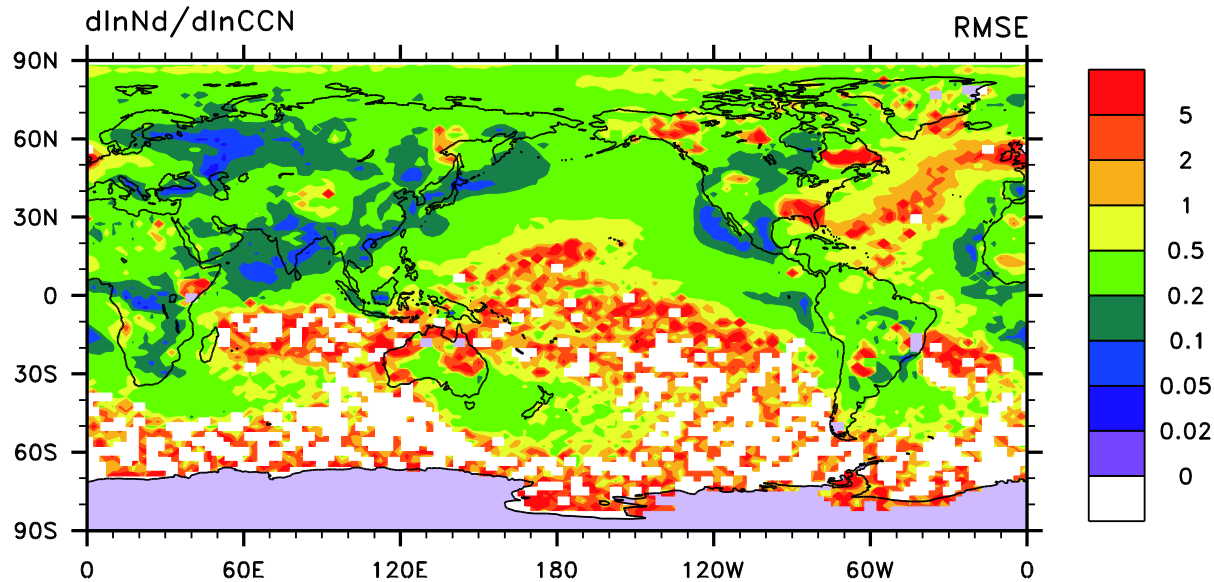
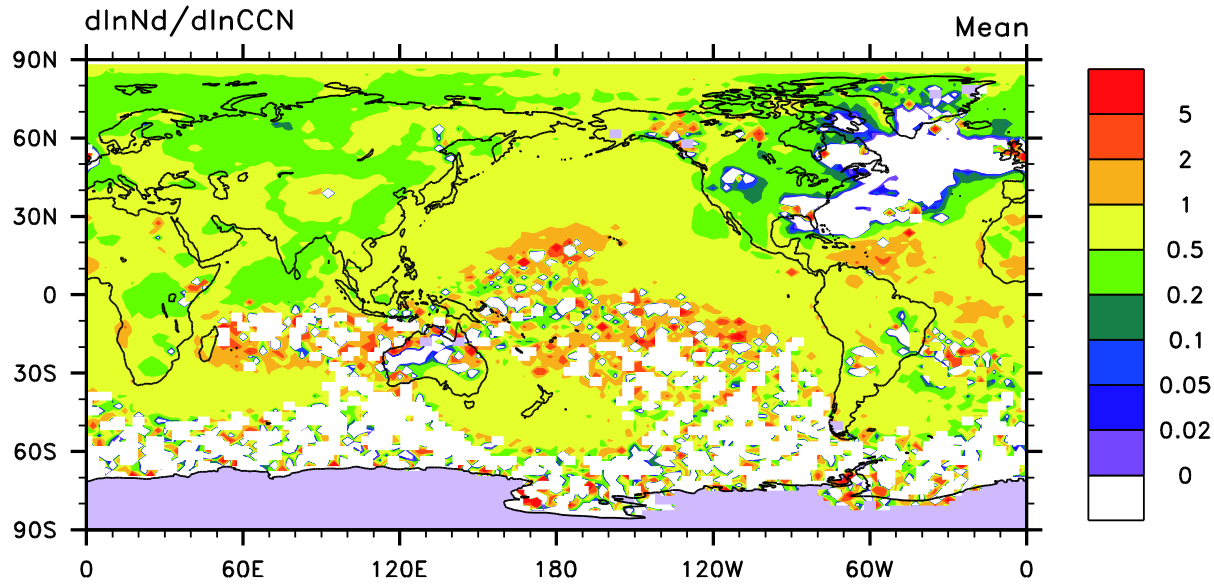


Mann et al., JGR (2014)

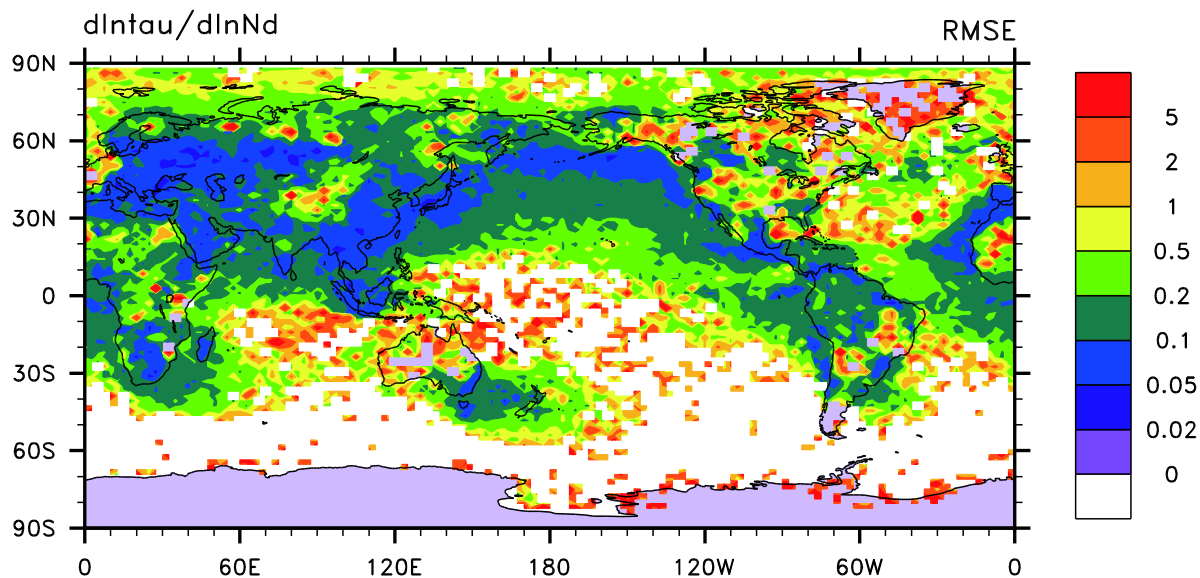
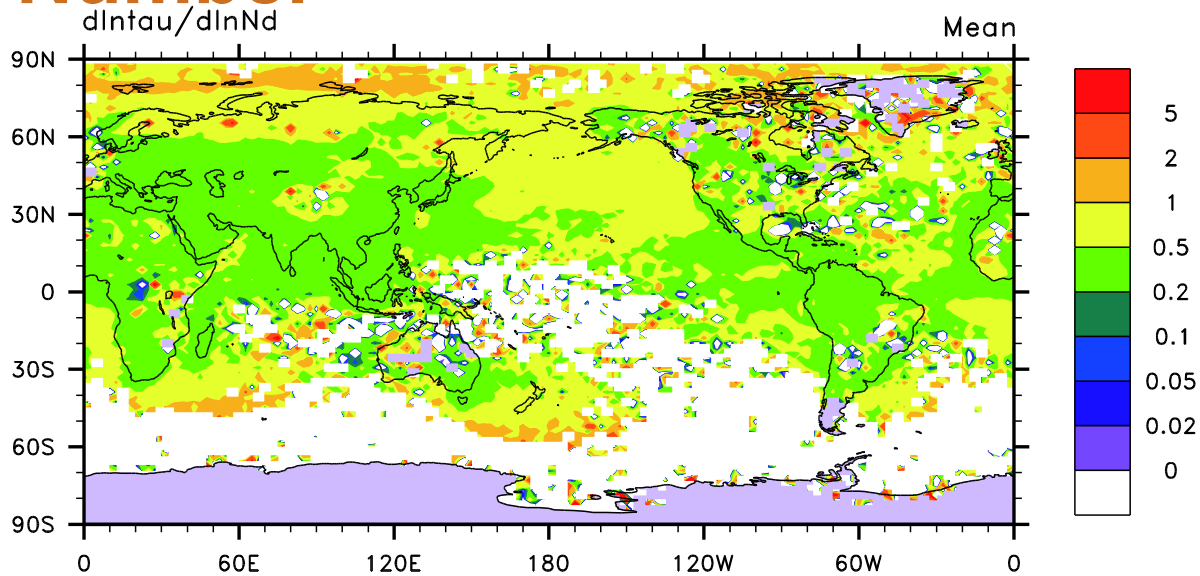
Spatial Distribution of Terms: Anthropogenic CCN



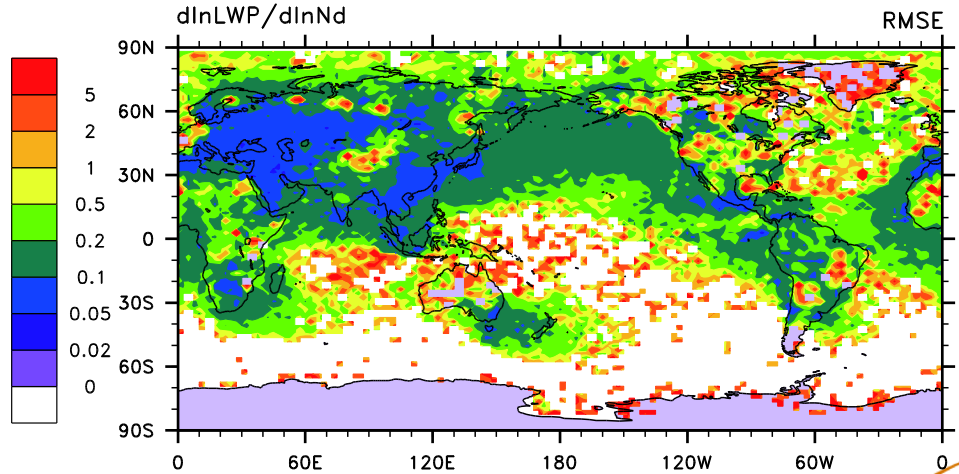
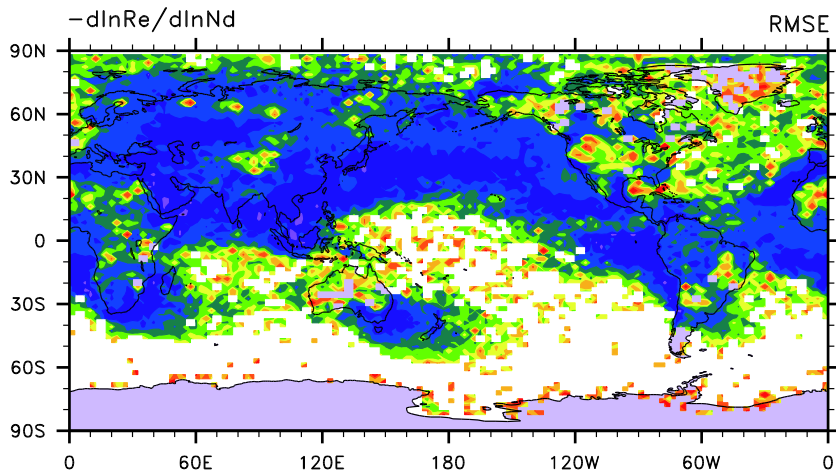
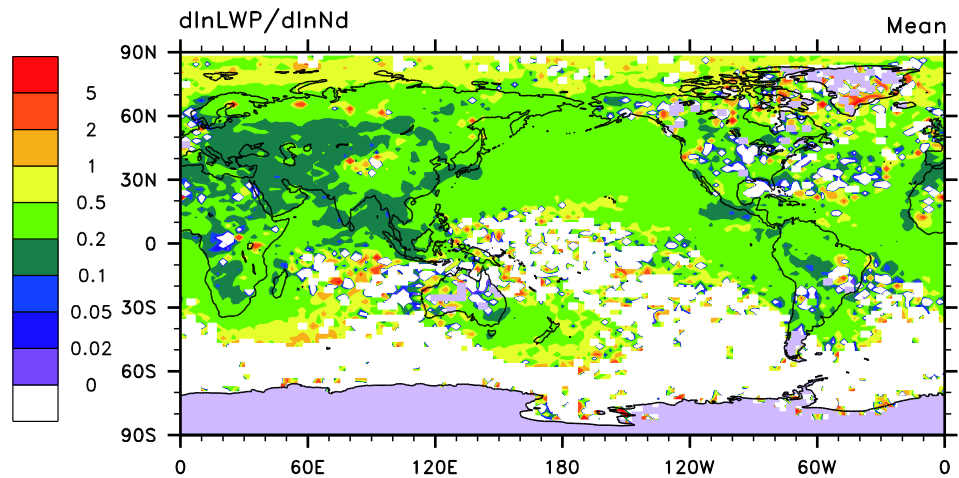
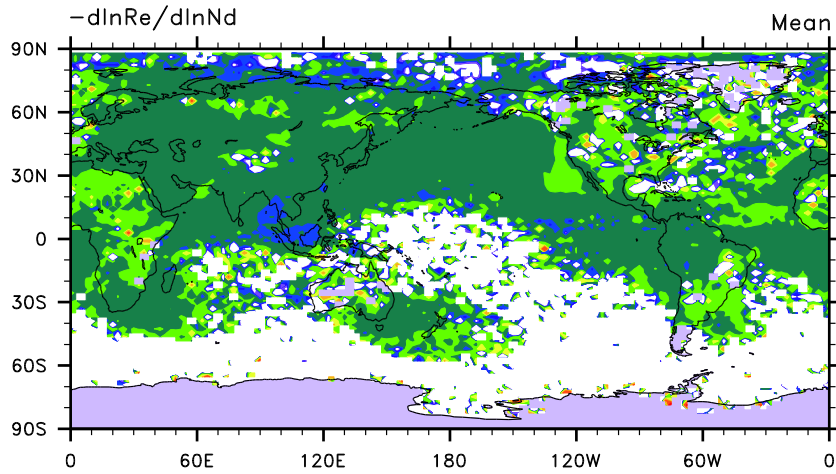
Droplet Number Sensitivity to CCN



Cloud Optical Depth Sensitivity to Droplet Number



Components of Cloud Optical Depth Sensitivity



Cloud Radiative Forcing Sensitivity to Cloud Optical Depth

