Constraining Estimates of Aerosol Effects on Clouds Simulated by Global Climate Models

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Factorization

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

R: "clean-sky" shortwave cloud forcing

ΔR: aerosol indirect forcing, aka ERFaci

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

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

$$\simeq -\frac{\partial \ln r_e}{\partial \ln N_d} + \frac{\partial \ln L}{\partial \ln N_d} \quad \Leftarrow \quad \tau \propto \frac{L}{r_e}$$

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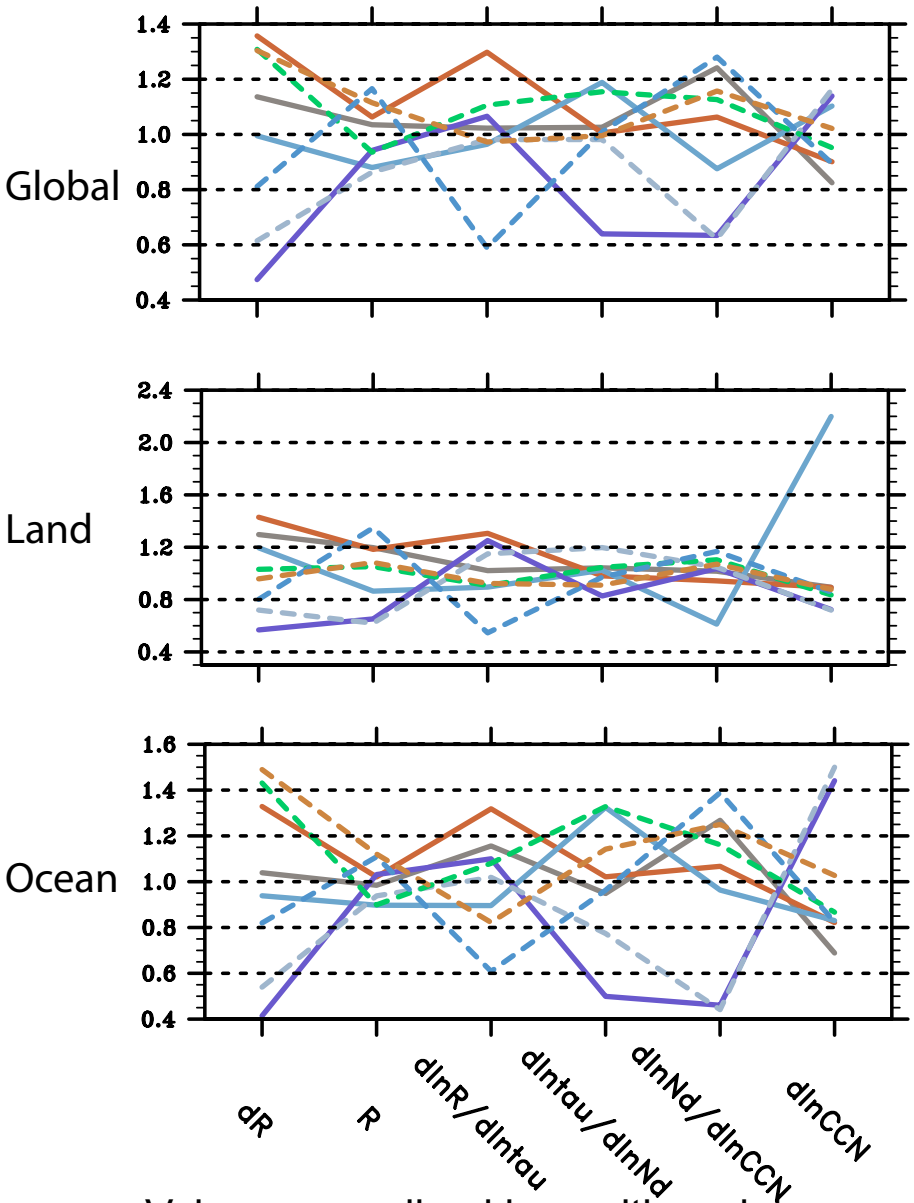
Factorization



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

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

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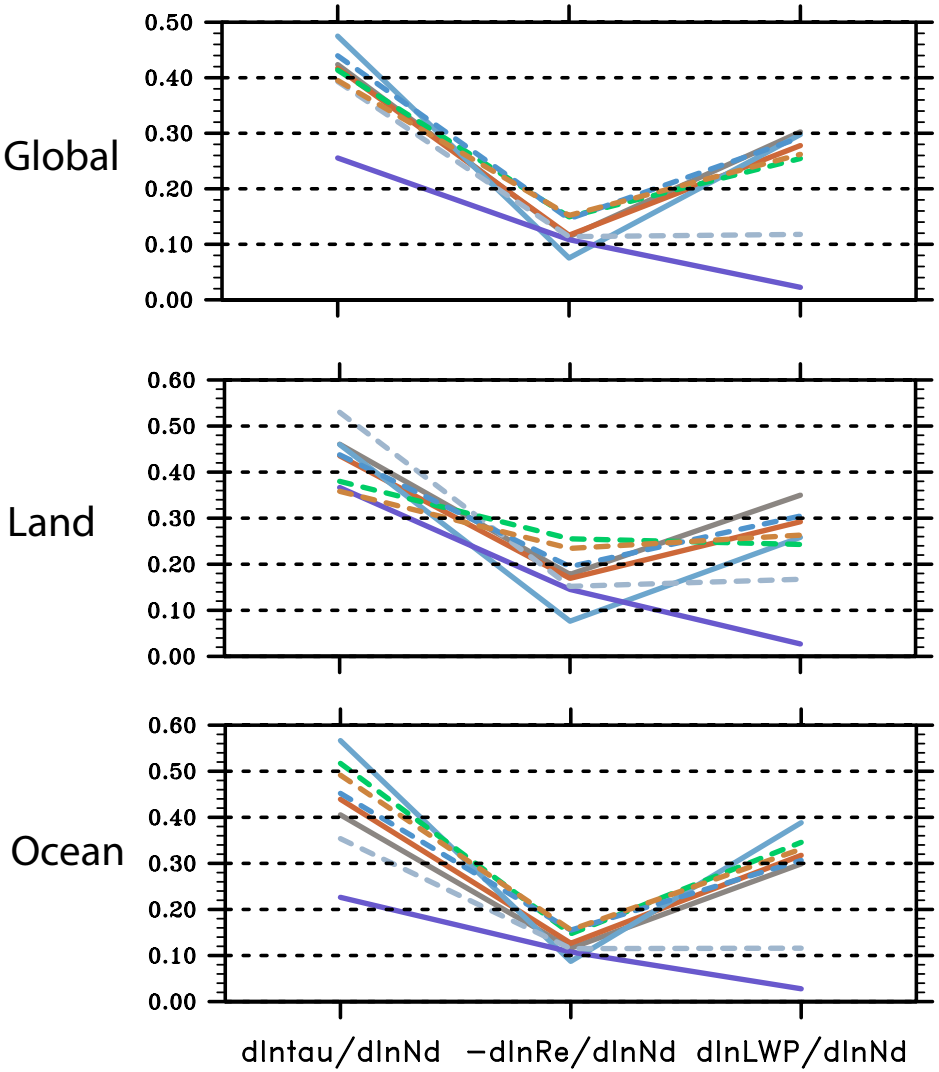
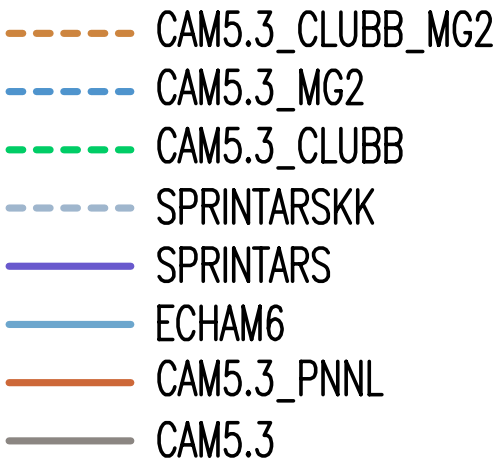
Decomposition: dlntau/dlnN$_d$





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

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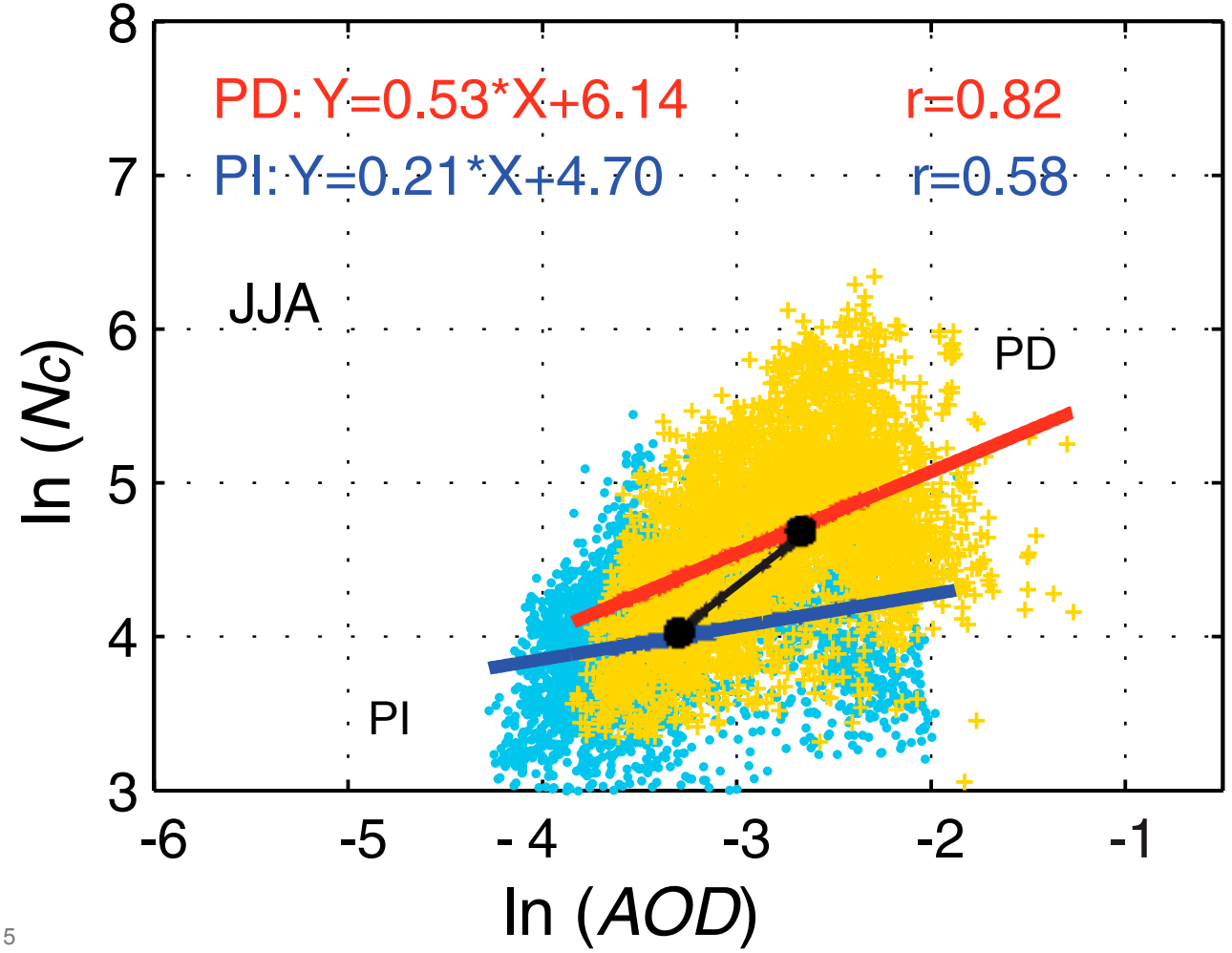
Constraints from present day variability might not apply to pre-industrial to present day changes



Penner et al., PNAS (2011)

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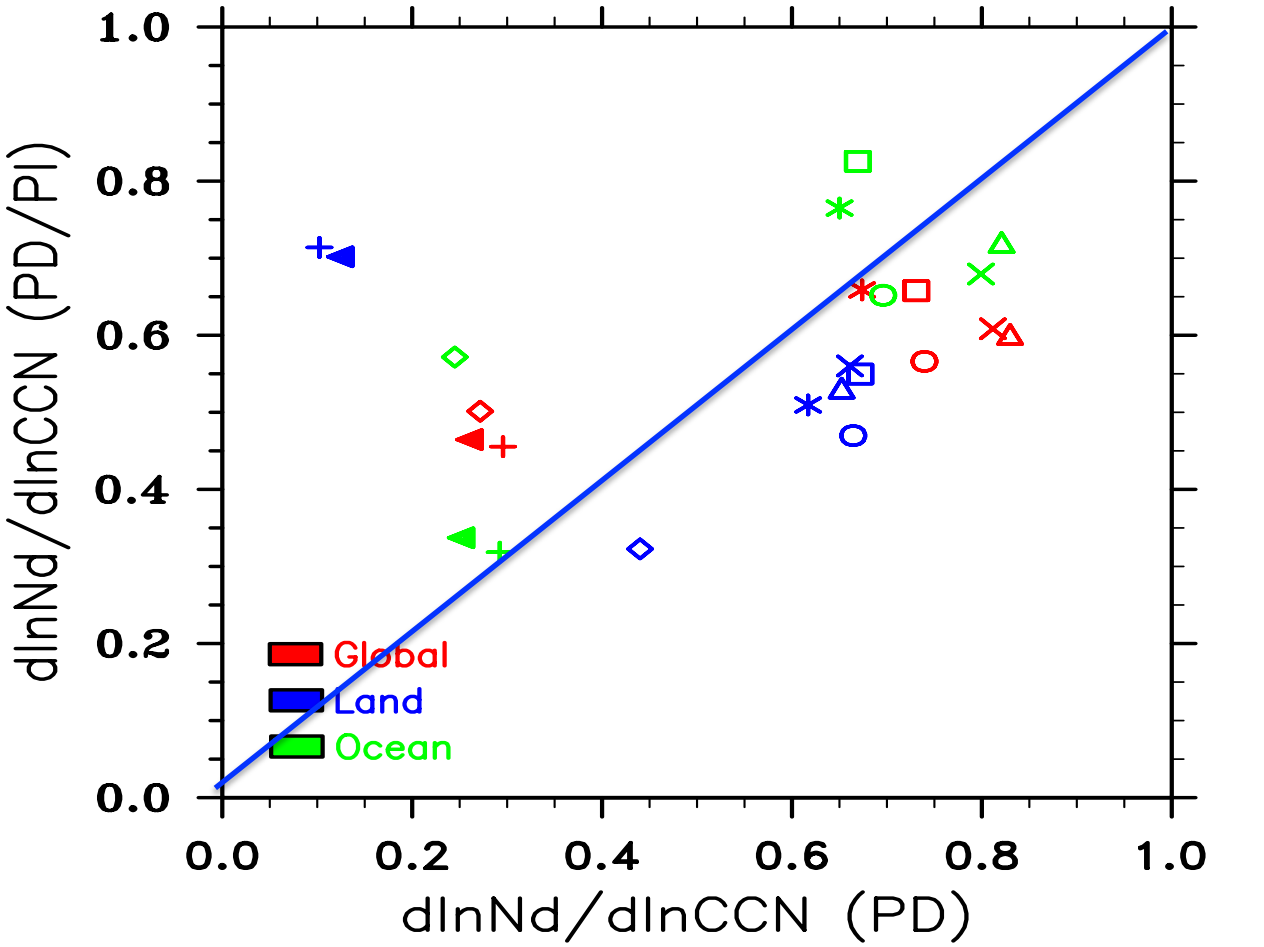
dlnNd/dlnCCN (PD) vs. dlnNd/dlnCCN (PD-PI)



✳ CAM5.3 ✕ CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2

◀ CAM5.3_PNNL ○ ETHZ–ECHAM6 ◇ SPRINTARS + SPRINTARSKK

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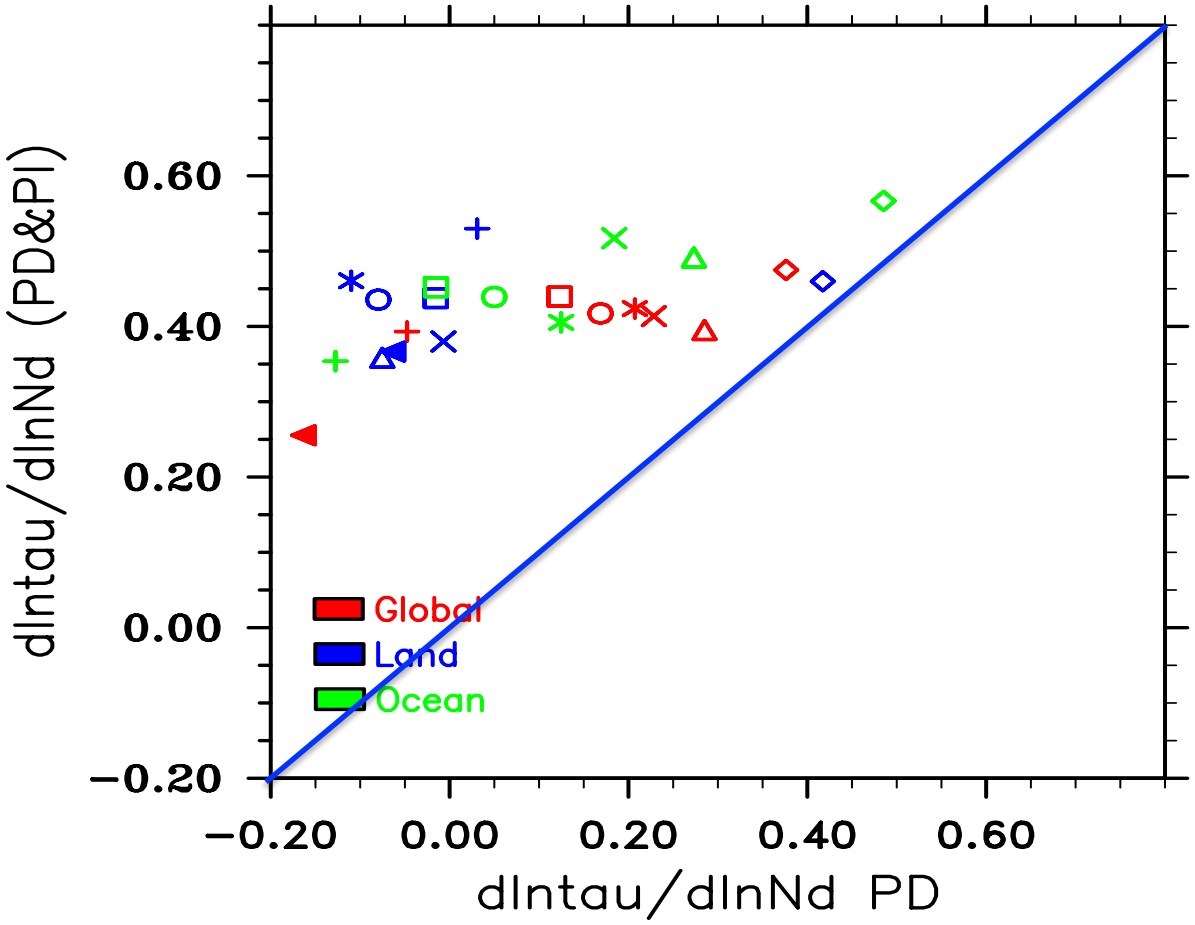
DIntau/dlnNd (PD) vs. dIntau/dlnNd (PD-PI)



✳ CAM5.3 ✕ CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2

◀ CAM5.3_PNNL ○ ETHZ−ECHAM6 ◇ SPRINTARS + SPRINTARSKK

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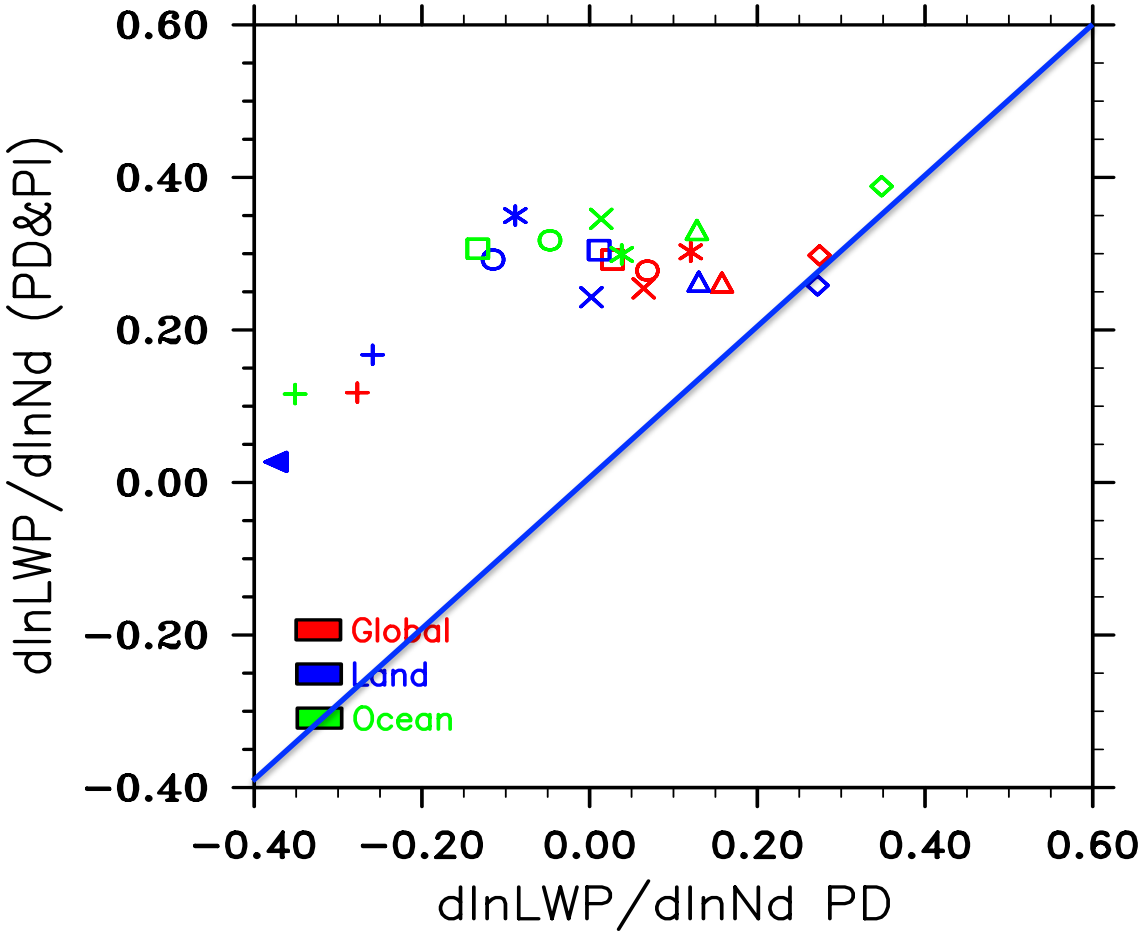
dlnLWP/dlnNd (PD) vs. dlnLWP/dlnNd (PD-PI)



∗ CAM5.3 × CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2

◀ CAM5.3_PNNL ○ ETHZ−ECHAM6 ◇ SPRINTARS + SPRINTARSKK

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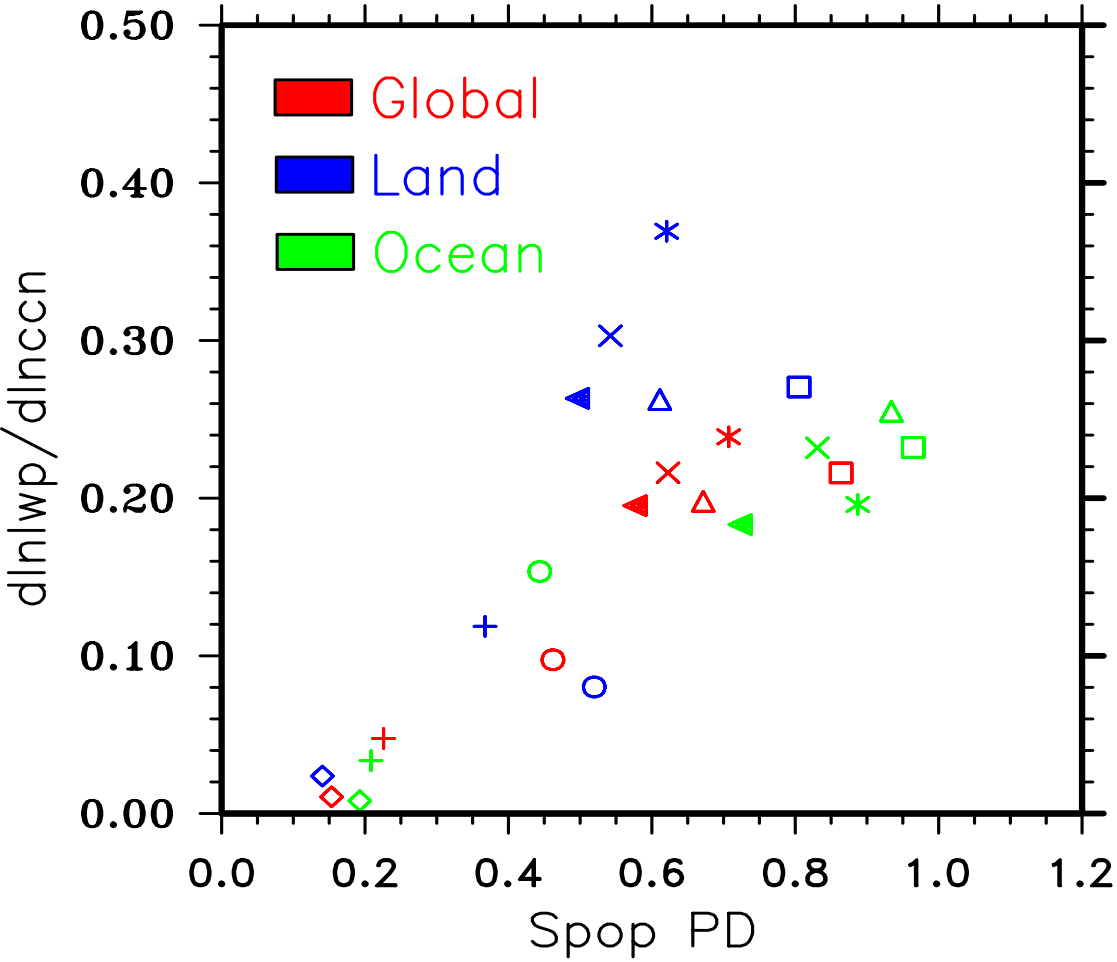
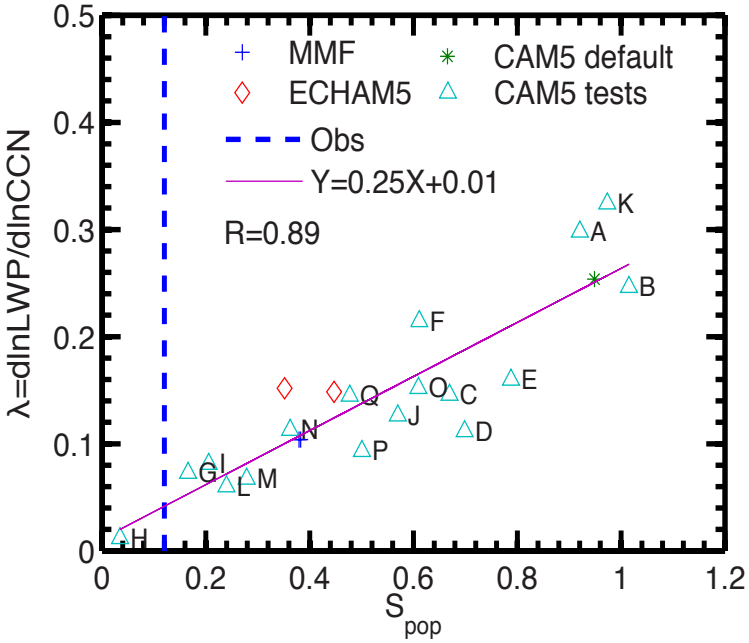
Spop vs. dlnLWP/dlnCCN (Pd-Pl)



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



Spop=-dlnPOP/dlnAI

∗ CAM5.3 × CAM5.3_CLUBB □ CAM5.3_MG2 △ CAM5.3_CLUBB_MG2
◀ CAM5.3_PNNL ○ ETHZ–ECHAM6 ◇ SPRINTARS + SPRINTARSKK

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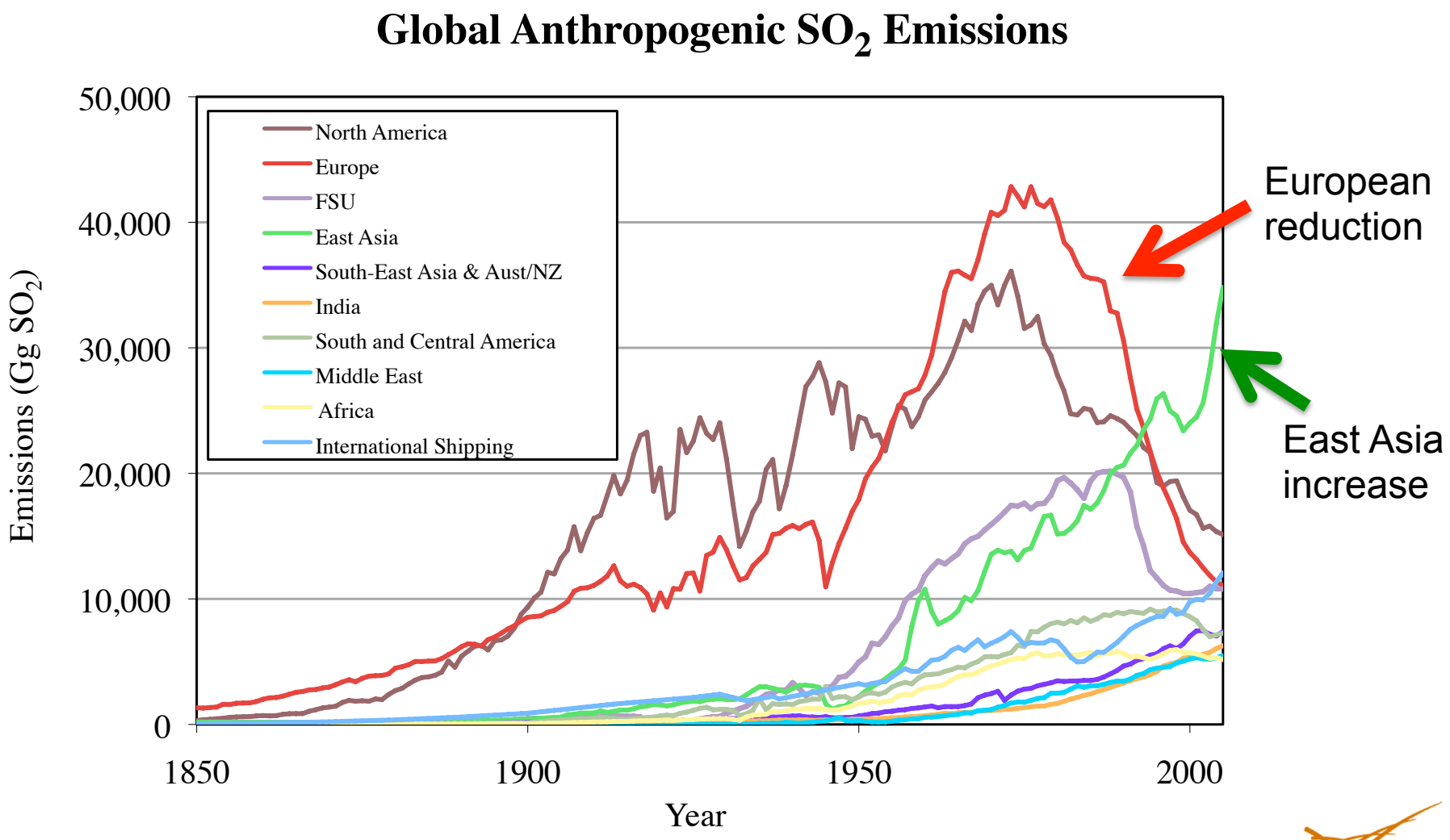
Opportunities from Recent Regional Changes in Emissions



Smith et al., ACP (2011)

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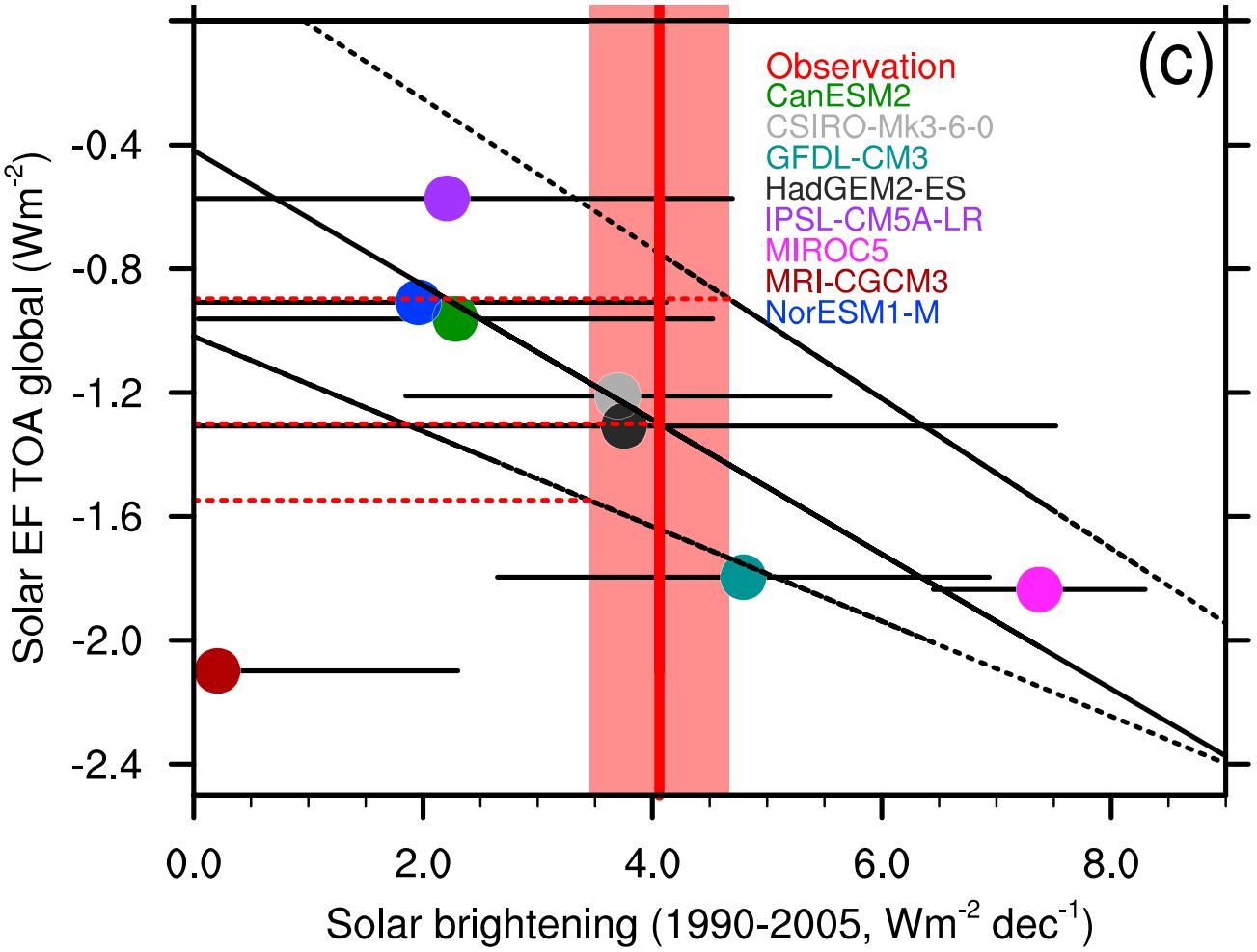
Constraining Forcing with Recent Changes

- Satellite data not available to constrain factors during this period



Cherian et al., GRL (2014)

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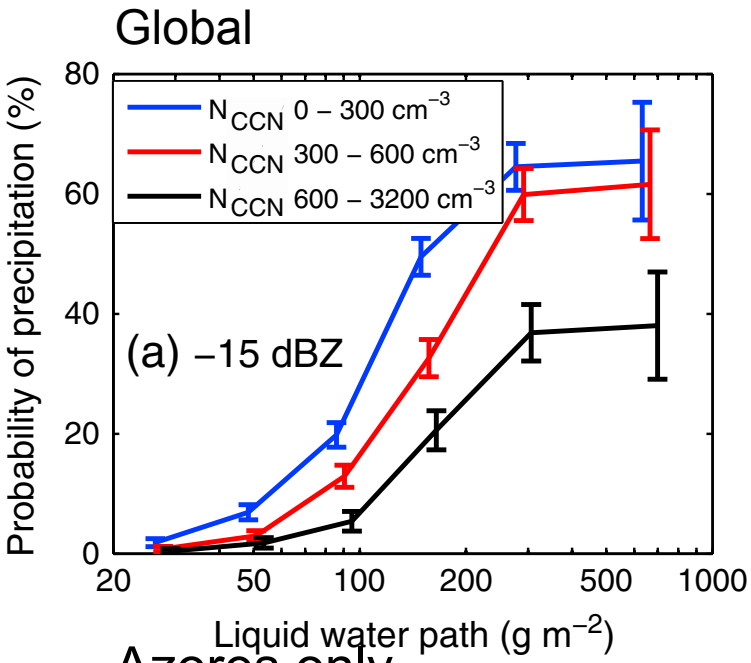
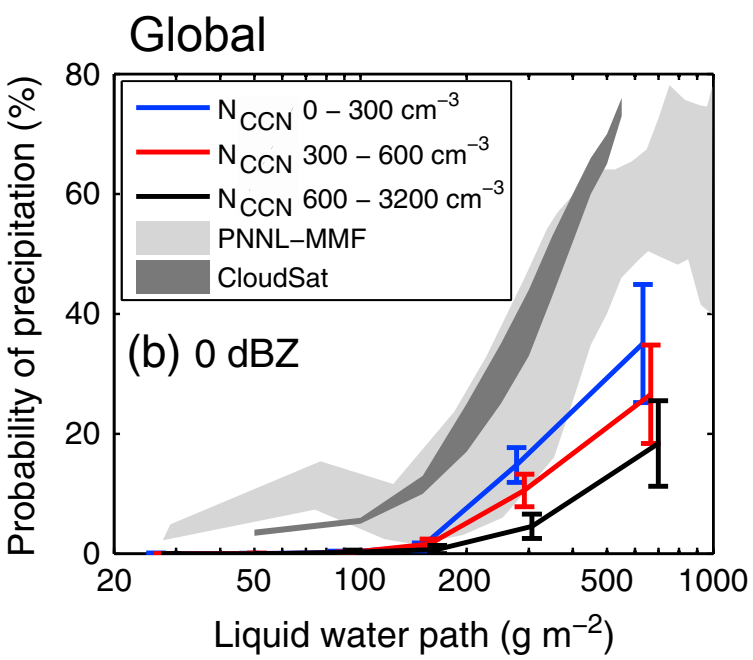
Conclusions

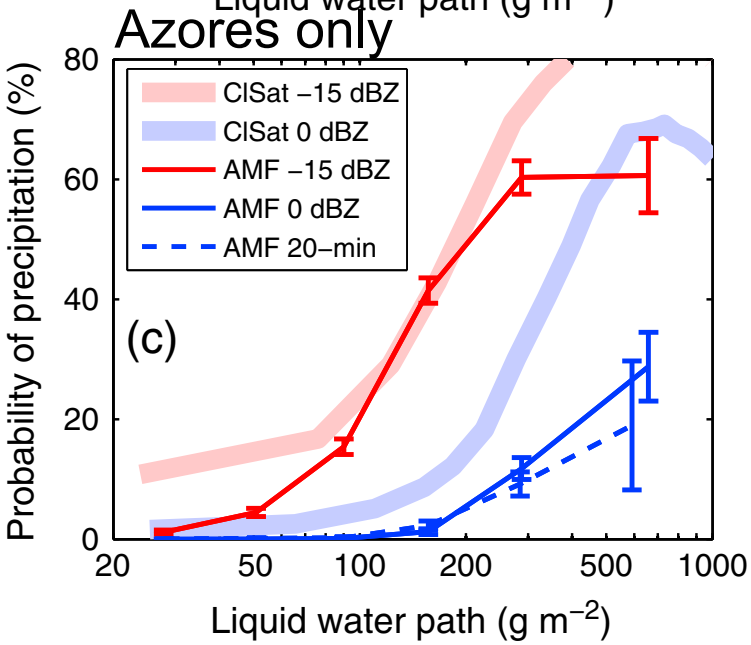
- Diversity in estimated effective radiative forcing through aerosol effects on clouds is driven by diversity in several factors, particularly
  - Sensitivity of droplet number to CCN
  - Sensitivity of liquid water path to droplet number
- Constraints on anthropogenic aerosol effects are needed
- Constraining susceptibilities 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)

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