On Constraining Effective Radiative Forcing by Cloud-Aerosol Interactions in Climate Models

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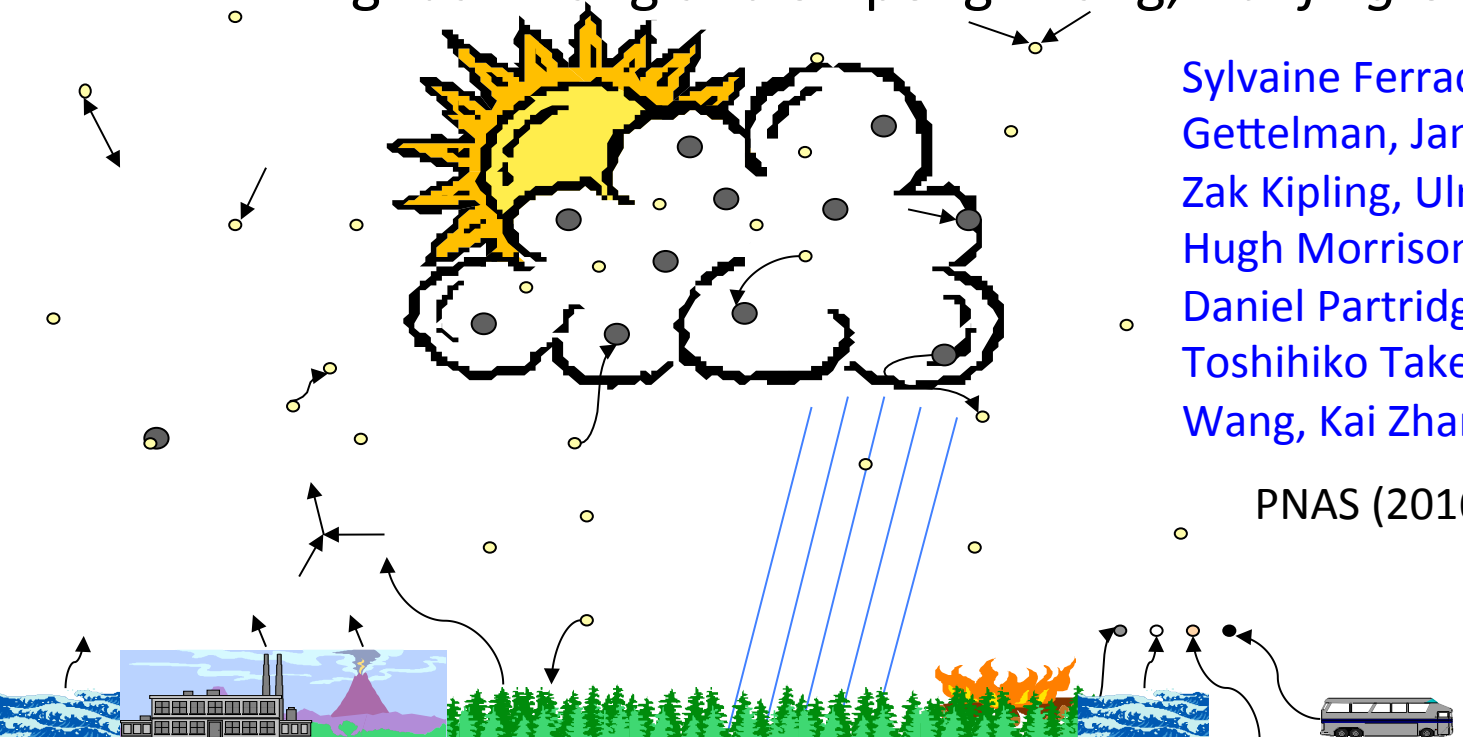


Sylvaine Ferrachat, Andrew Gettelman, Jan Griesfeller, Zak Kipling, Ulrike Lohmann, Hugh Morrison, David Neubauer, Daniel Partridge, Philip Stier, Toshihiko Takemura, Hailong Wang, Kai Zhang

PNAS (2016)

AeroCom

Key Questions

- Why has it been so difficult to make progress on quantifying aerosol-cloud interactions for climate assessments?
- What can be done to make progress moving forward?

Sums and Factors

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

$$= R\left(\frac{d\ln C}{d\ln N_d}+\frac{d\ln R_c}{d\ln \tau_c}\frac{d\ln \tau_c}{d\ln N_d}\right)\frac{d\ln N_d}{d\ln CCN}\frac{d\ln CCN}{d\ln E}\Delta\ln E \qquad R=CR_c$$

R: "clean-sky" shortwave cloud forcing (Ghan, ACP, 2013)

ΔR: ERFaci N_d: cloud droplet number

CCN: CCN at 1 km (0.3% supersaturation) E: anthropogenic emission

R_c: in-cloud R C: cloud fraction

τ_c: cloud optical depth r_e: droplet effective radius L: liquid water path

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

$$\simeq -\frac{d\ln r_e}{d\ln N_d}+\frac{d\ln L}{d\ln N_d} \quad \Leftarrow \quad \tau_c \propto \frac{L}{r_e}$$

albedo effect — lifetime effect

Anthropogenic Change

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

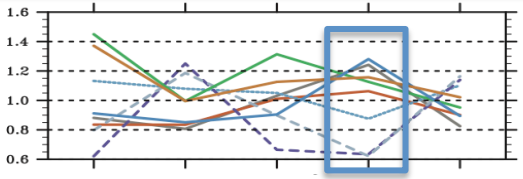
$$= R \left(\frac{\Delta \ln C}{\Delta \ln N_d} + \frac{\Delta \ln R_c}{\Delta \ln \tau_c} \frac{\Delta \ln \tau_c}{\Delta \ln N_d} \right) \frac{\Delta \ln N_d}{\Delta \ln CCN} \frac{\Delta \ln CCN}{\Delta \ln E} \Delta \ln E$$

$$\frac{\Delta \ln \tau_c}{\Delta \ln N_d} = \frac{\partial \ln \tau_c}{\partial \ln r_e} \frac{\Delta \ln r_e}{\Delta \ln N_d} + \frac{\partial \ln \tau_c}{\partial \ln L} \frac{\Delta \ln L}{\Delta \ln N_d}$$

$$\simeq - \frac{\Delta \ln r_e}{\Delta \ln N_d} + \frac{\Delta \ln L}{\Delta \ln N_d}$$

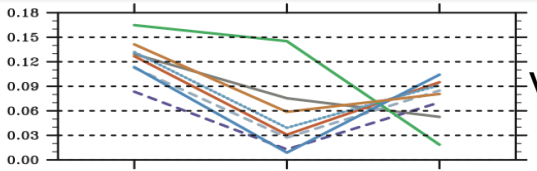
albedo effect

lifetime effect



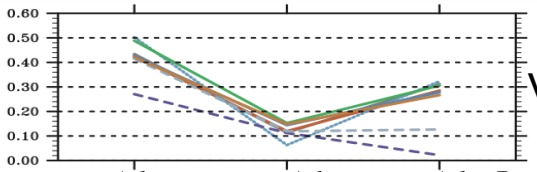
Values normalized by multi-model mean

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



Values not normalized

$$\frac{\Delta \ln R}{\Delta \ln N_d} = \frac{\Delta \ln C}{\Delta \ln N_d} + \frac{\Delta \ln R_c}{\Delta \ln \tau}\frac{\Delta \ln \tau}{\Delta \ln N_d}$$



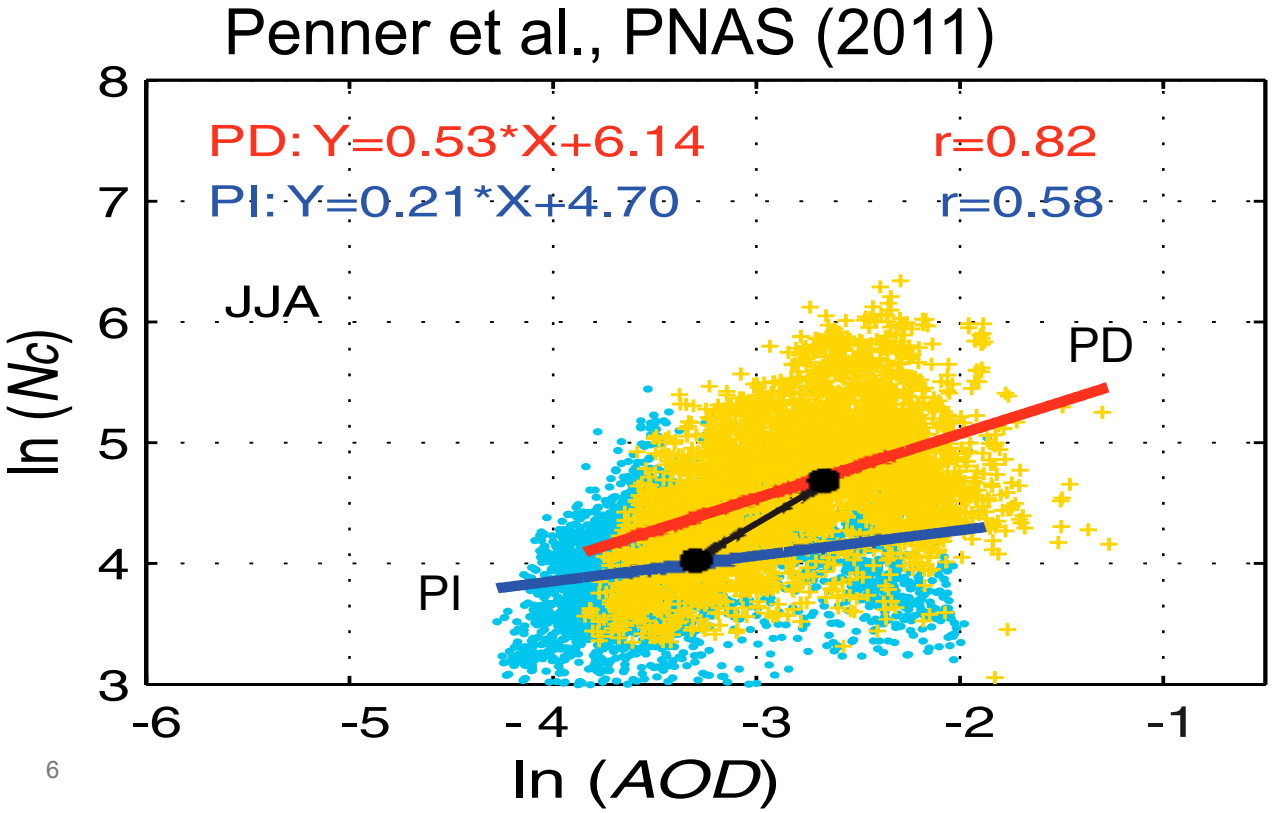
Values not normalized

$$\frac{\Delta \ln \tau_c}{\Delta \ln N_d} \simeq -\frac{\Delta \ln r_e}{\Delta \ln N_d} + \frac{\Delta \ln L}{\Delta \ln N_d}$$

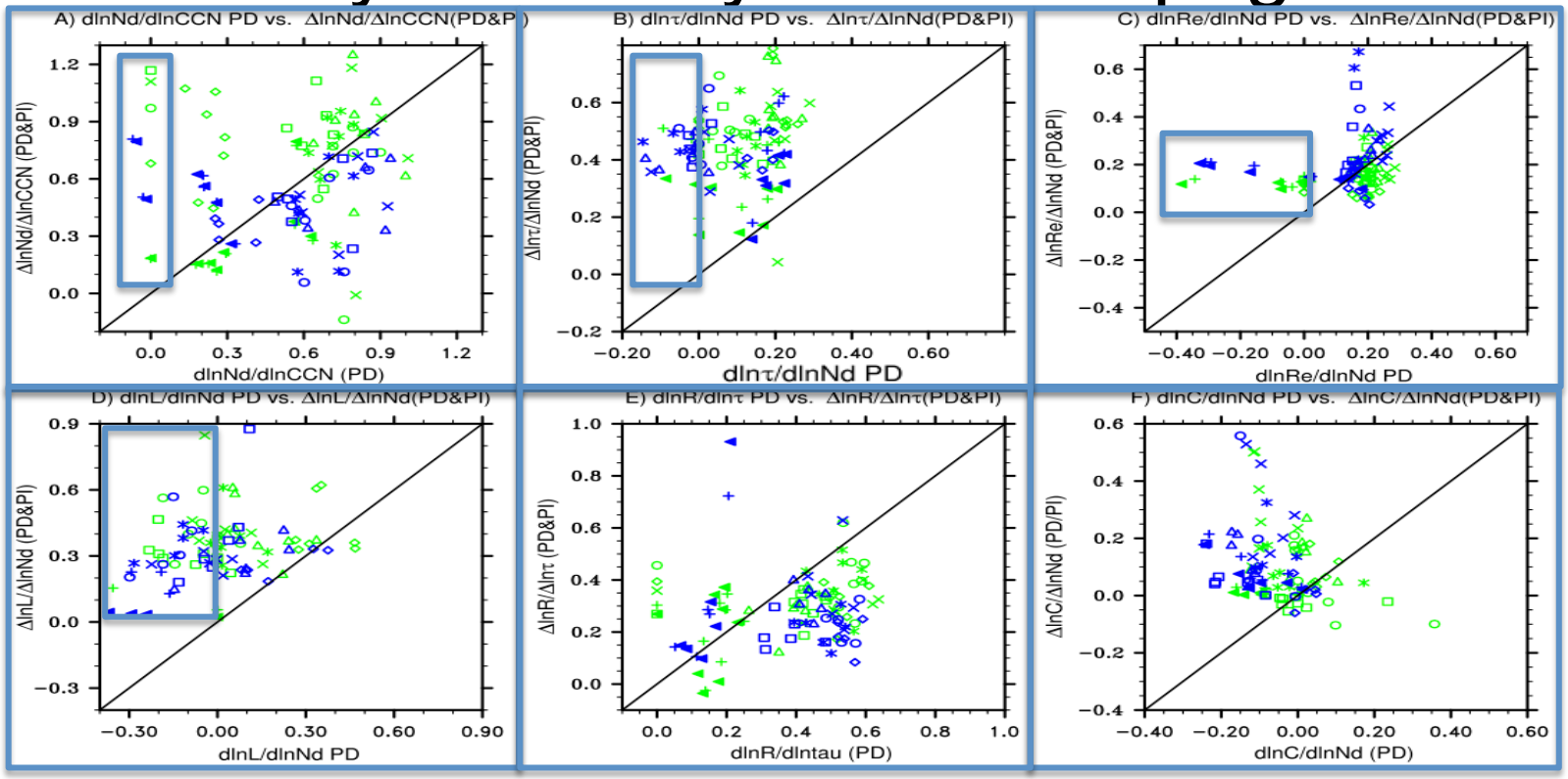
CAM5.3
CAM5.3_CLUBB_MG2
CAM5.3_MG2
CAM5.3_CLUBB
SPRINTARSKK
SPRINTARS
ECHAM6
CAM5.3_PNNL

Which terms drive model diversity?

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



Present day variability vs. anthropogenic change

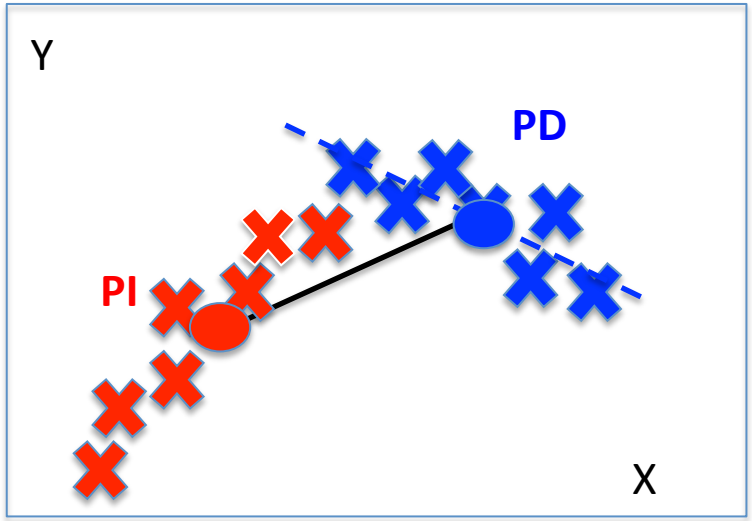


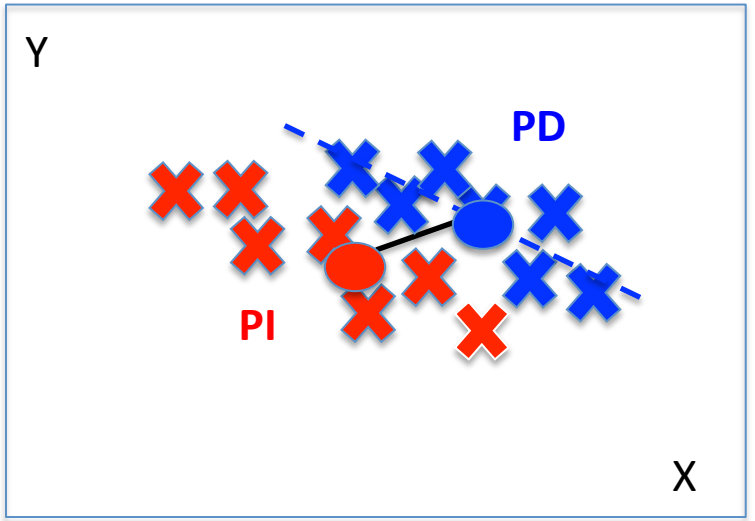
What can be done to make progress moving forward?

- Understand why $\Delta \ln X / \Delta \ln Y$ ne $d \ln X / d \ln Y$

Understand why ΔlnX/ΔlnY ne dlnX/dlnY

- Is the inconsistency due to lack of pre-industrial conditions in present day? In which regions and for which model is the disagreement greatest? What do the distributions of X and Y look like?



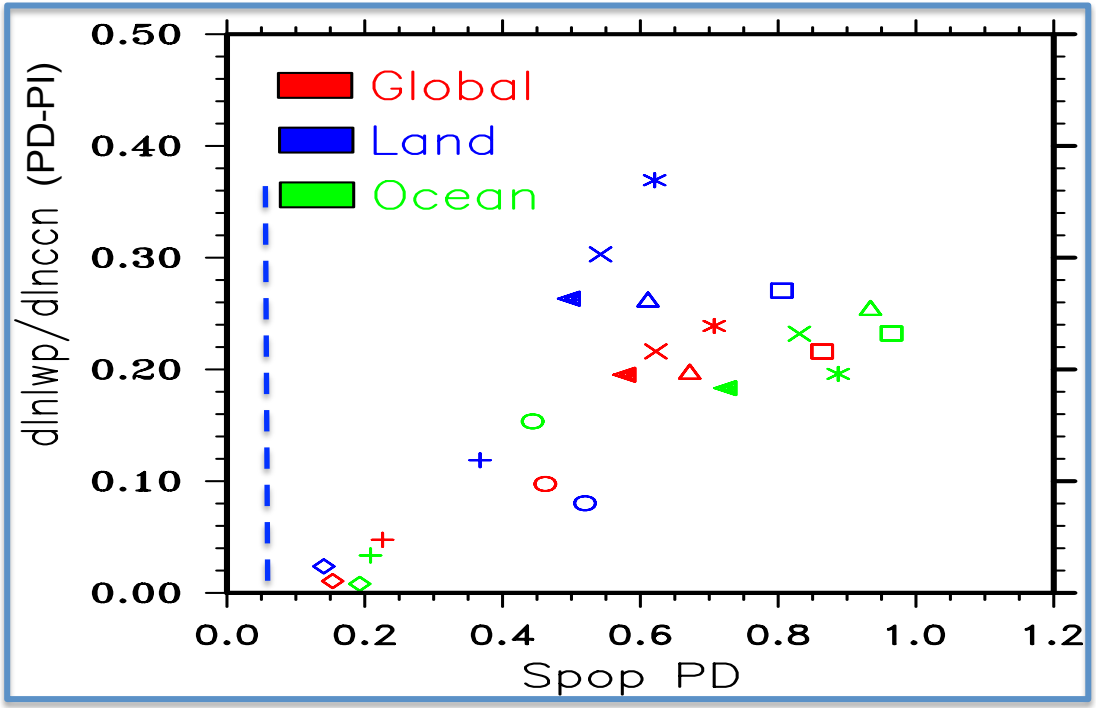


What can be done to make progress moving forward?

- Understand why ΔlnX/ΔlnY ne dlnX/dlnY
- Develop metrics that relate anthropogenic change to present day observables

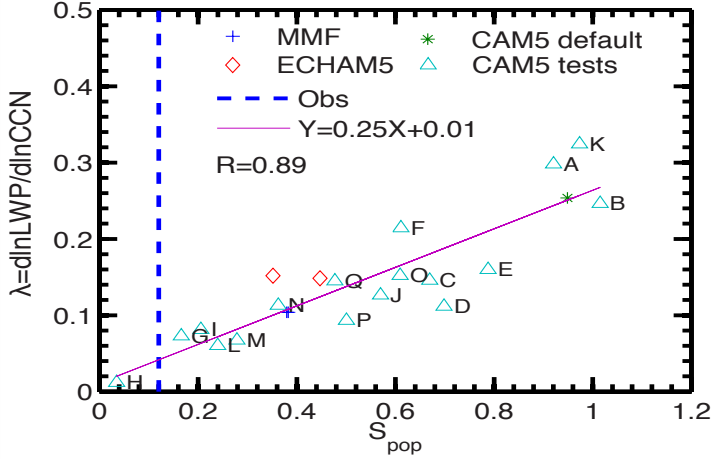
Relating anthropogenic change to present day observables

S_{pop} vs. dlnLWP/dlnCCN (PD-PI)



Over ocean

Wang et al., GRL (2012)



Spop=-dlnPOP/dlnAI

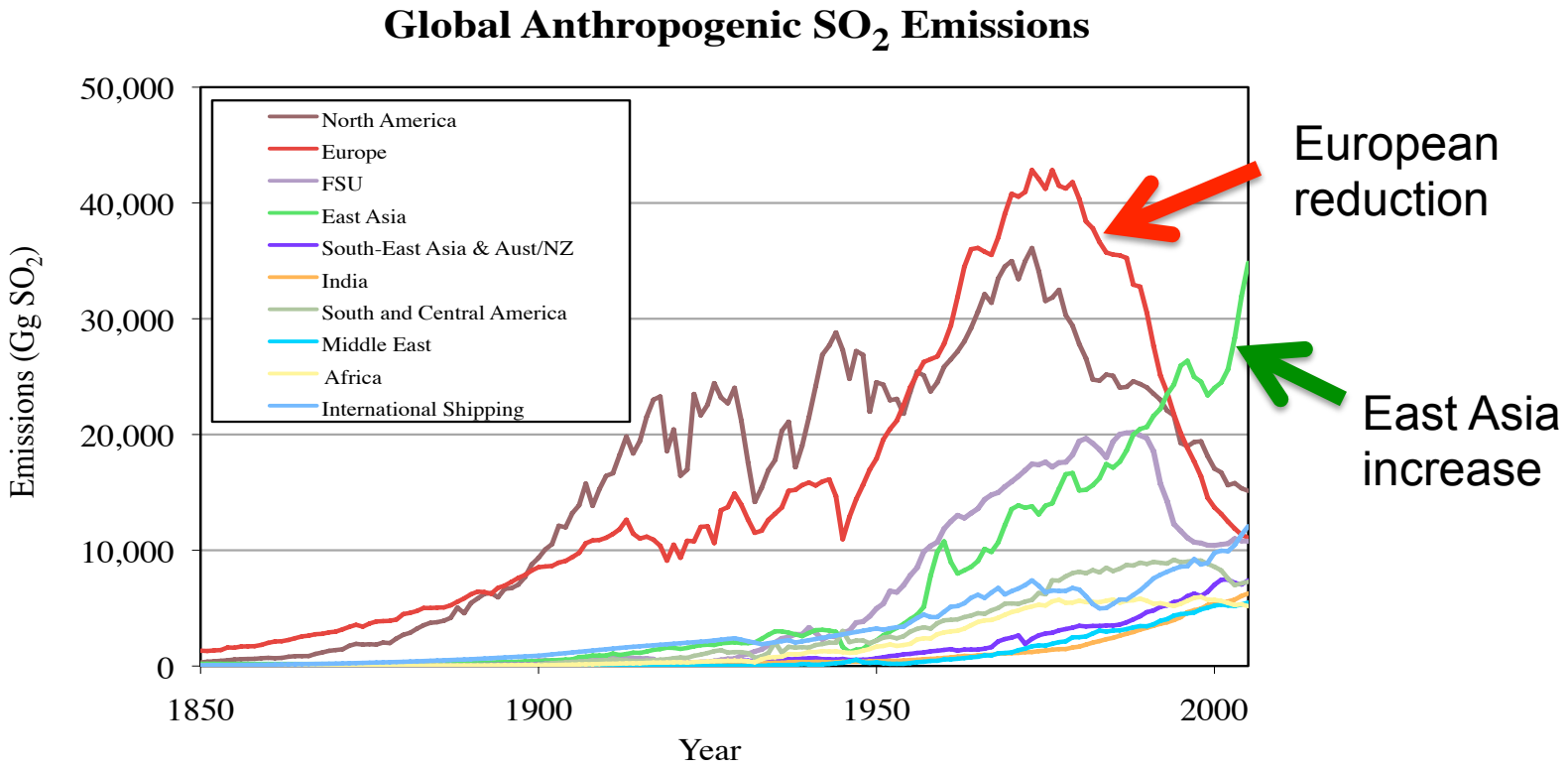
CAM5.3 CAM5.3_CLUBB CAM5.3_MG2 CAM5.3_CLUBB_MG2

CAM5.3_PNNL ETHZ–ECHAM6 SPRINTARS SPRINTARSKK

What can be done to make progress moving forward?

- Understand why ΔlnX/ΔlnY ne dlnX/dlnY
- Develop metrics that relate anthropogenic change to present day observables
- Use measurements where/when aerosol has changed

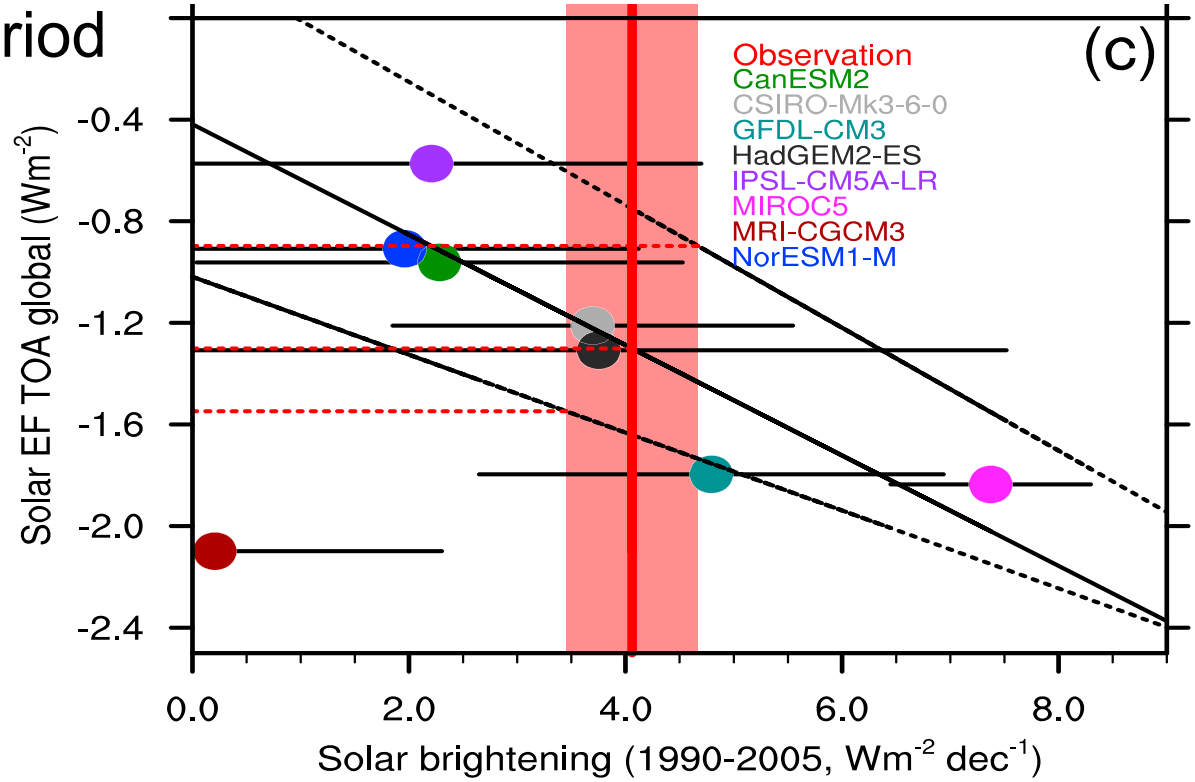
Opportunities from Recent Regional Changes in Emissions



Smith et al., ACP (2011)

Constraining Forcing with Recent Changes

- Satellite data not available to constrain factors during this period



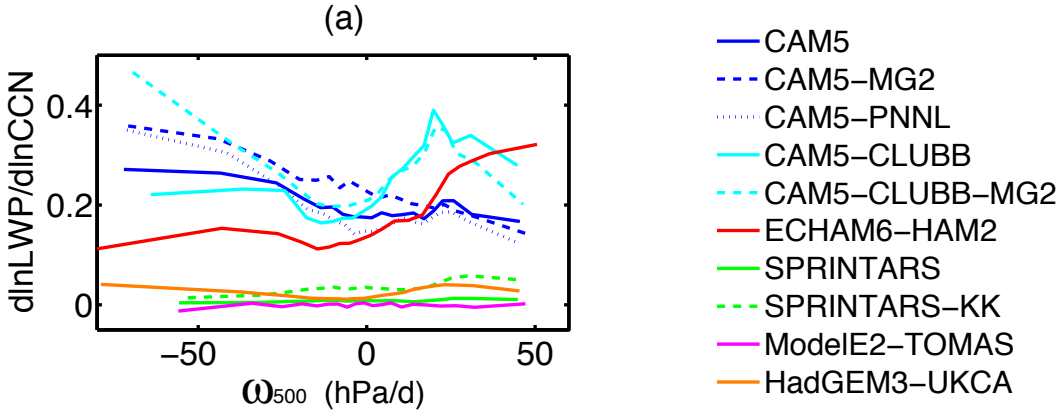
Cherian et al., GRL (2014)

What can be done to make progress moving forward?

- Understand why ΔlnX/ΔlnY ne dlnX/dlnY
- Develop metrics that relate anthropogenic change to present day observables
- Use measurements where/when aerosol has changed
- Apply measurements to cloud regimes

Focus on cloud regimes

- The cloud feedback community has reduced uncertainty by exploiting cloud variations stratified by cloud regime
- Could the same approach benefit CAPI



S. Zhang et al., ACP (2016)

Conclusions

- Diversity in estimated effective radiative forcing through aerosol effects on clouds is driven by diversity in several factors
- Constraints on anthropogenic aerosol effects are needed for each factor
- Constraining sensitivities using data from present day variability often insufficient to constrain anthropogenic aerosol effects. This needs to be understood better.
- New present day metrics are needed to constrain anthropogenic aerosol effects
- Regional trends for selected periods could be helpful
- Global satellite data availability limits trend analysis of factors to post 2002
- Haywood et al. study of SO_2 emissions from Iceland volcano in 2014
- Analysis by cloud regime could be helpful