15th CAS-TWAS-WMO Forum & 15th AeroCOM/4th AeroSat Workshop

Emergent Constraints for Aerosol Indirect Effect

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09/19/2016, Beijing, China

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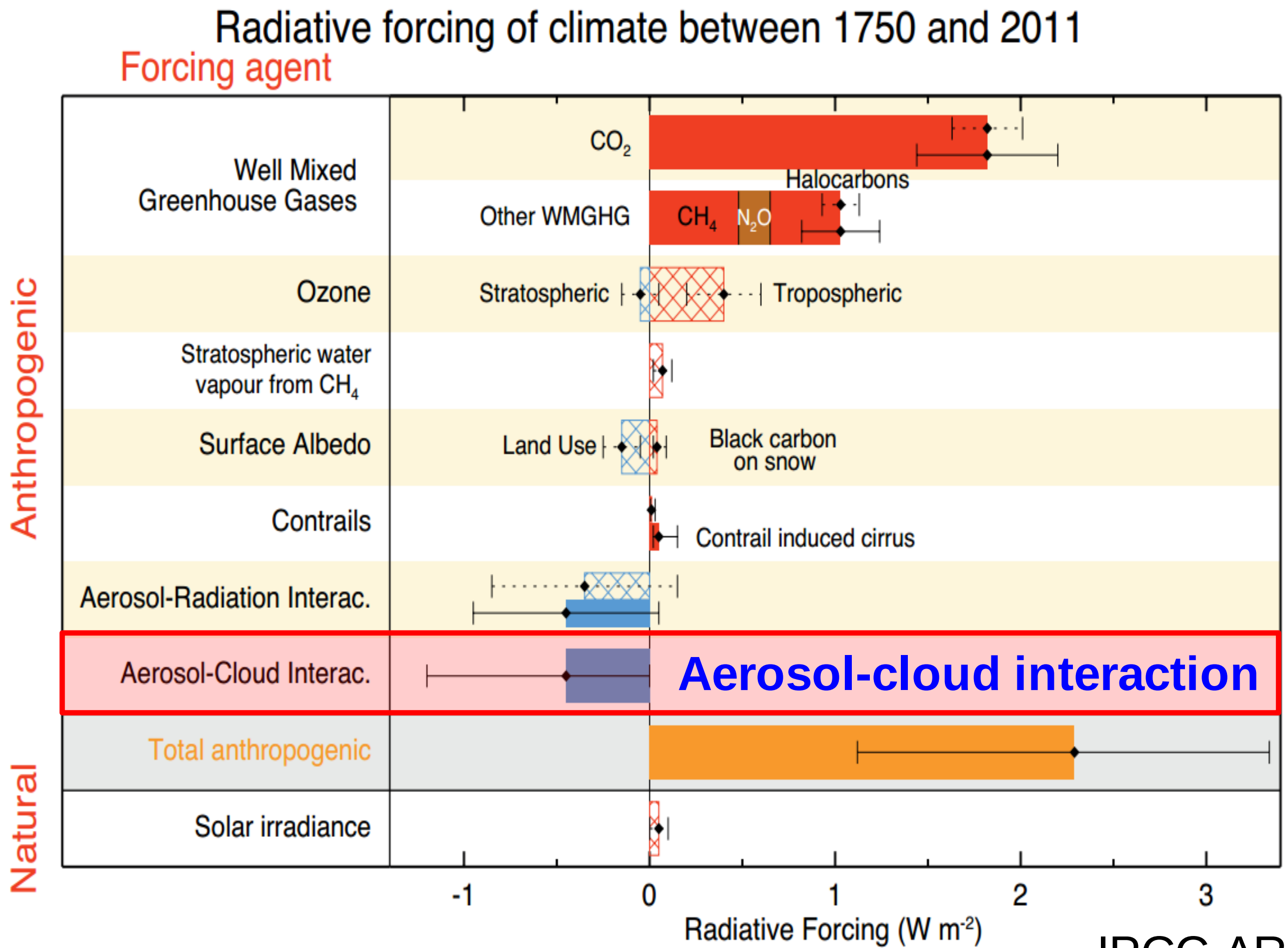
Uncertainties in radiative forcing come primarily from aerosol radiative forcing



IPCC AR5

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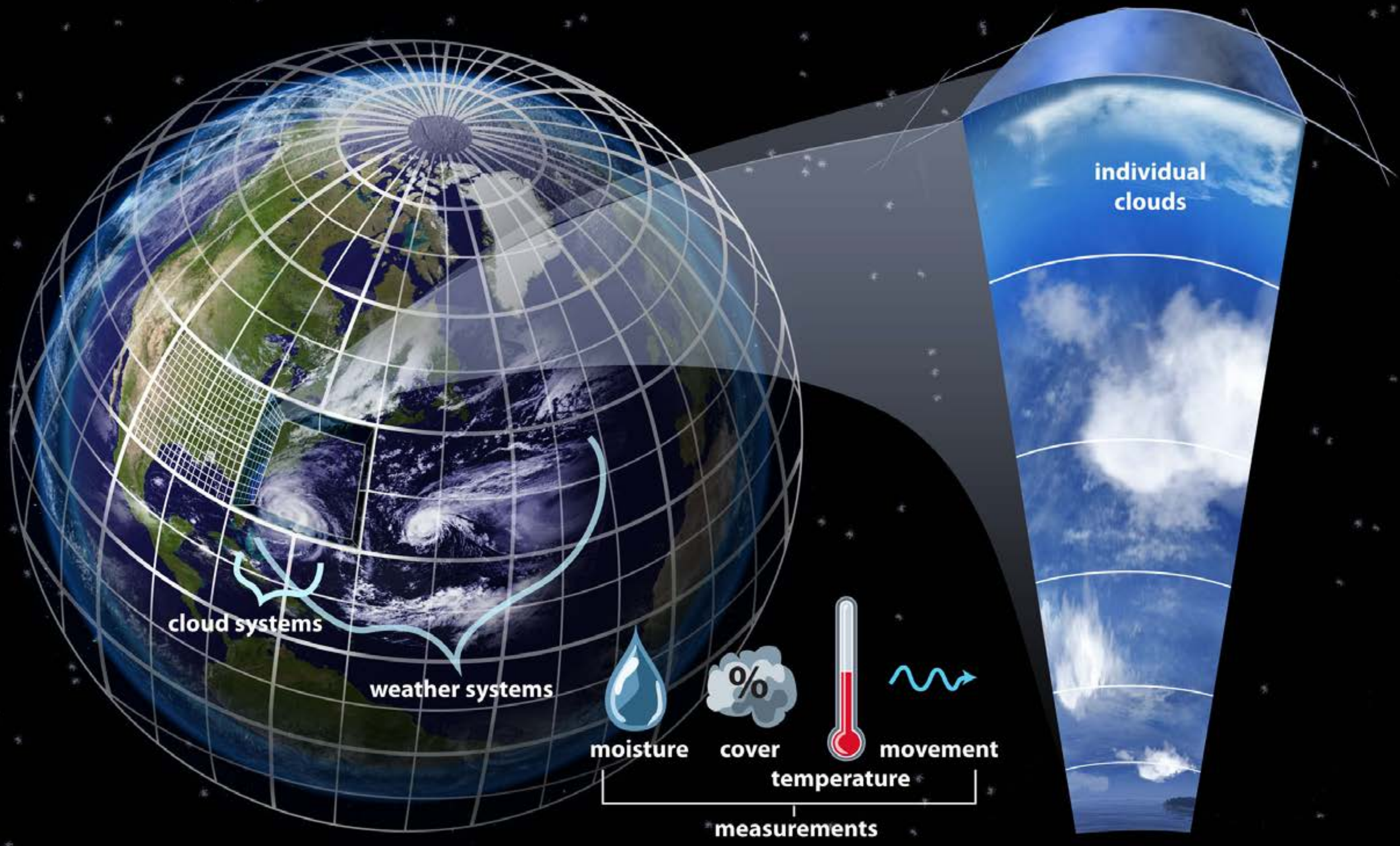
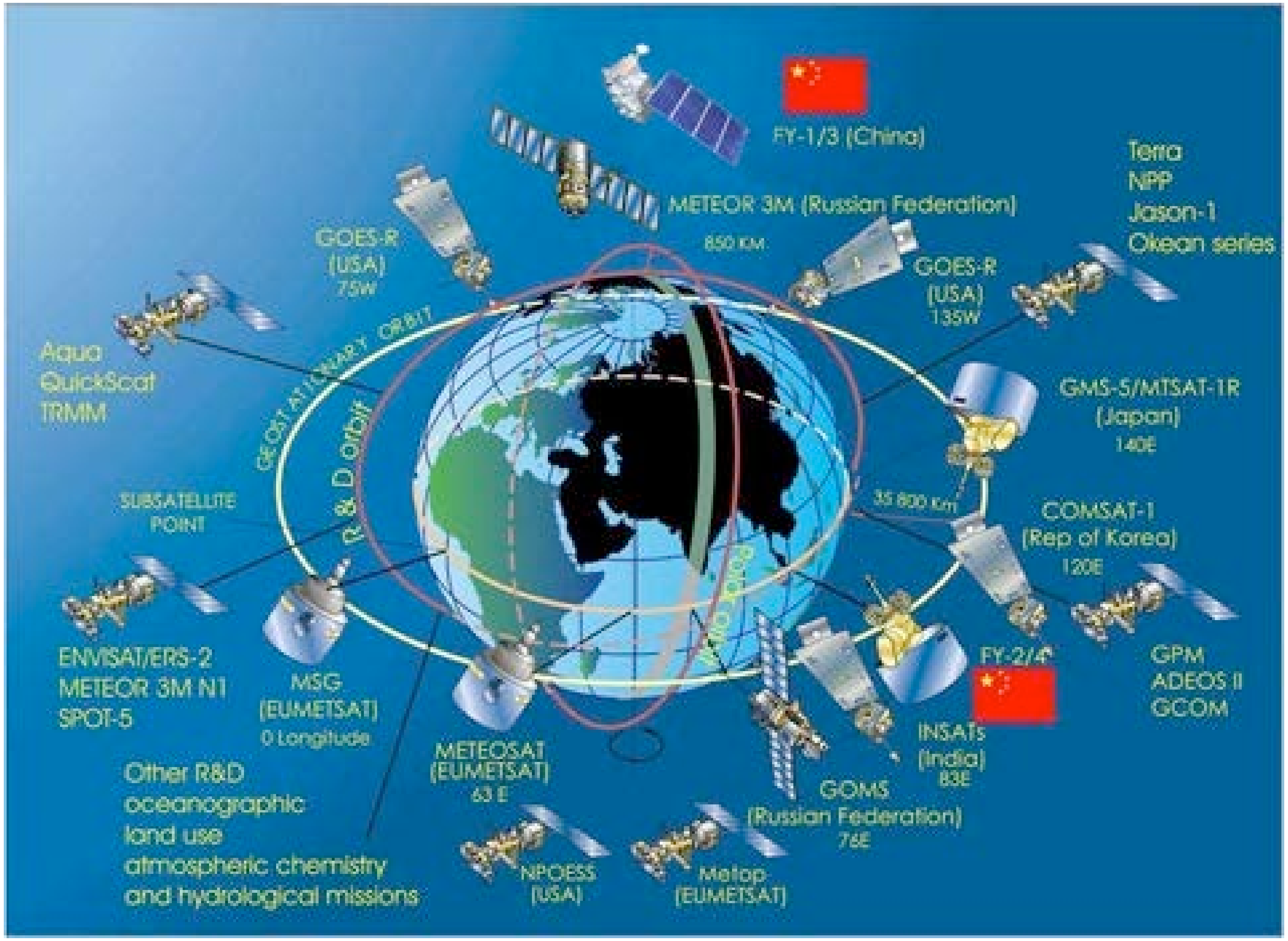
Climate Models: indispensible tools for studying aerosol climate effects, but with limitations in representing aerosol-cloud interactions



Observations are critical for evaluating and improving climate models



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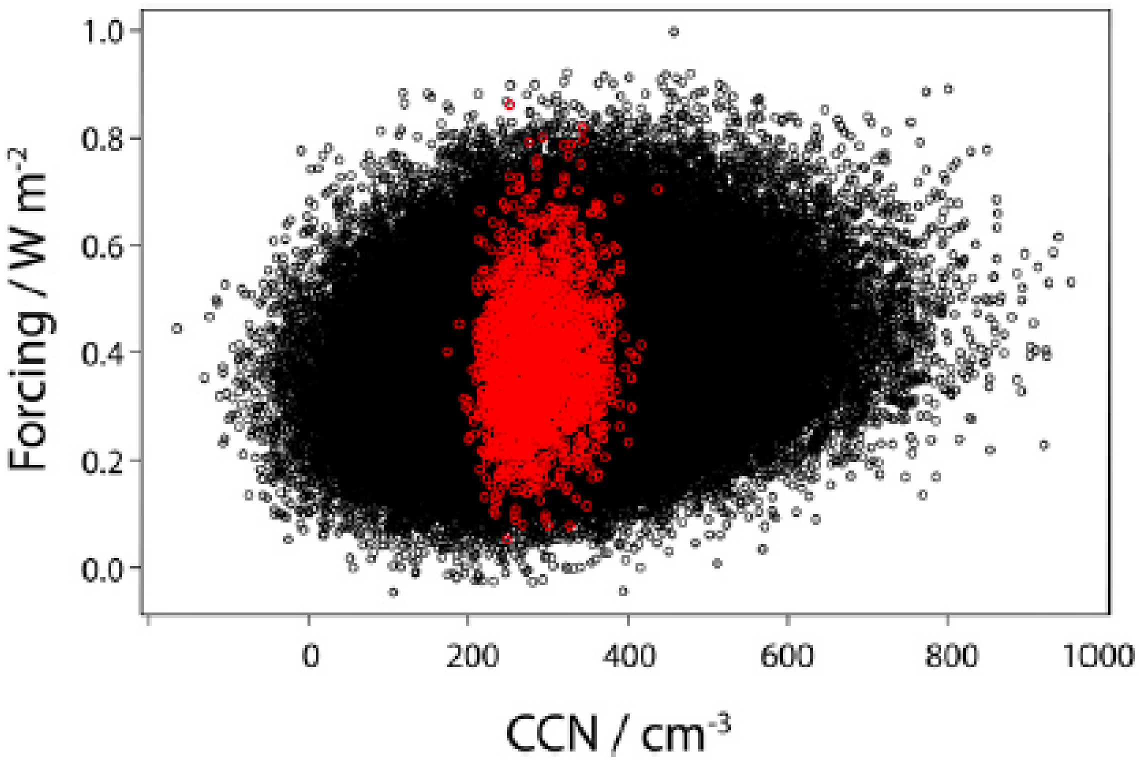
Direct constraints on model states are inefficient for constraining aerosol indirect forcing

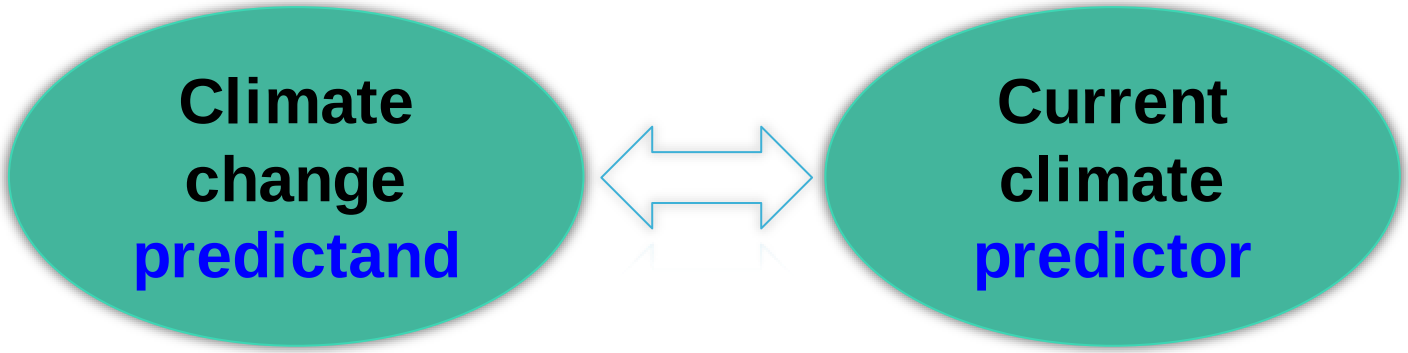


Lee et al., 2016, PNAS

- Constraining CCN in current climate does not necessarily narrowing the estimate of aerosol indirect forcing

Emergent constraints

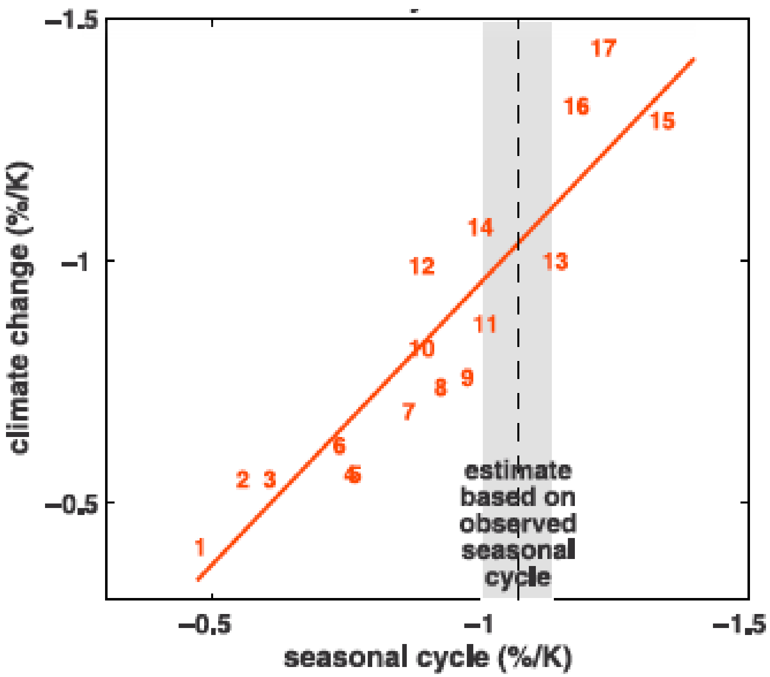
- Definition: Physically explainable empirical relationship between characteristics of the current climate and long-term climate prediction that emerge in collections of climate model simulations (Klein and Hall, 2015, Curr. Clim. Change Rep.)



- Three types of emergent constraints:
  - Potential emergent constraints (simple relationship)
  - Promising emergent constraints (physical basis for relationship)
  - Confirmed emergent constraints (physical understanding is credible)

Emergent constraints in climate feedback studies

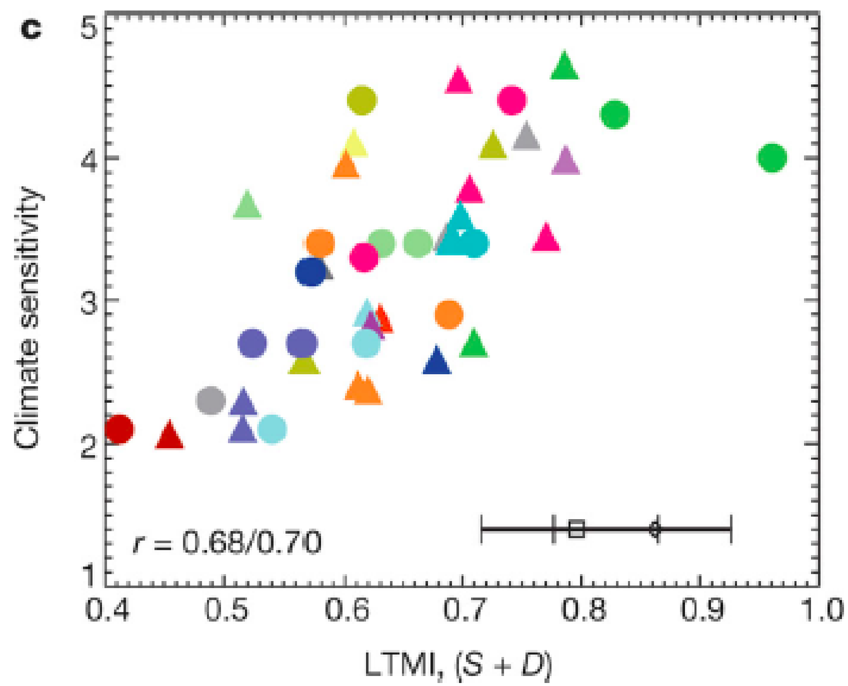
Snow-albedo feedback



Hall and Xu, 2006, GRL

- Predictor: albedo change from seasonal cycle
- Predictand: albedo changes from climate change

Cloud feedback



Sherwood et al., 2014, Nature

- Predictor: lower tropospheric mixing over oceans
- Predictand: climate sensitivity

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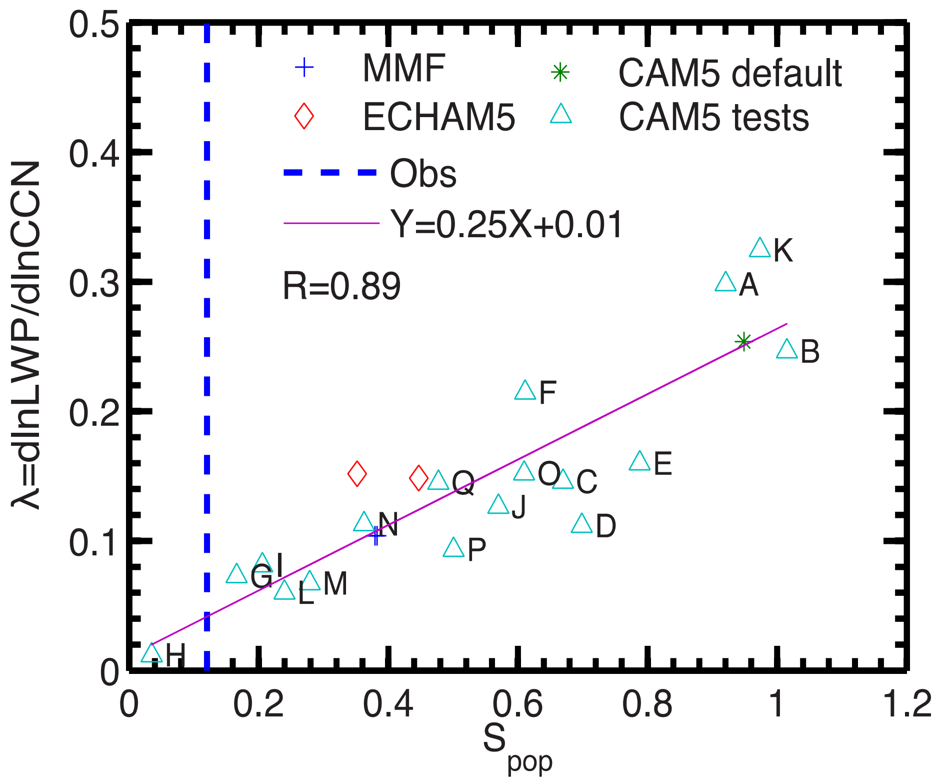
S_{POP}: An emergent constraint for aerosol cloud lifetime effects of aerosols



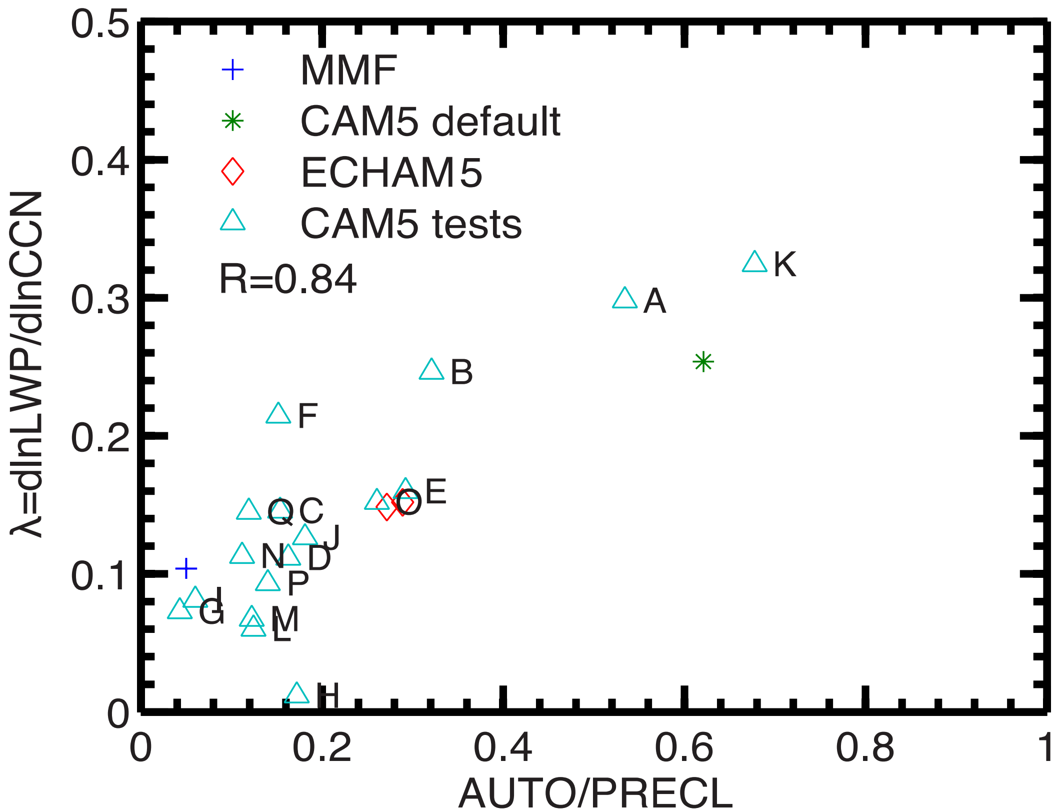
S_{POP}=-dlnPOP/dlnAI

POP: Probability of precipitation （raining clouds divided by all clouds）
AI ：Aerosol Index

M. Wang et al., 2012, *GRL*

- Predictor: S_{POP} from the present-day climate
- Predictand: Liquid water path change in response to CCN changes from PI to PD (cloud lifetime effects of aerosols)

Physically explainable: Both S_{POP} and λ strongly depends on the relative role of autoconversion in rain formation.



S_{POP}: promising emergent constraint or confirmed emergent constraint?

The 3rd AeroCOM indirect effect intercomparison project

- Main objective: To study cloud lifetime effects of aerosols in global aerosol-climate models, especially those used in CMIP5 (led by Steve Ghan and Minghuai Wang)

- Model runs: two runs (5 years each), All_2000 (PD, present day) and All_1850 (PI, pre-industrial)

- Participants: CAM5.3 and its variants (5 versions); ETH-ECHAM6-HAM2; SPRINTARS;HadGEM3-UKCA; ModelE2-TOMAS; GFDL AM3

Publications: two papers published (S. Zhang et al., 2016, ACP; S. Ghan et al., 2016, PNAS); several are in preparation (E. Gryspeerdet et al, 2016; M. Wang et al., 2016; ...)

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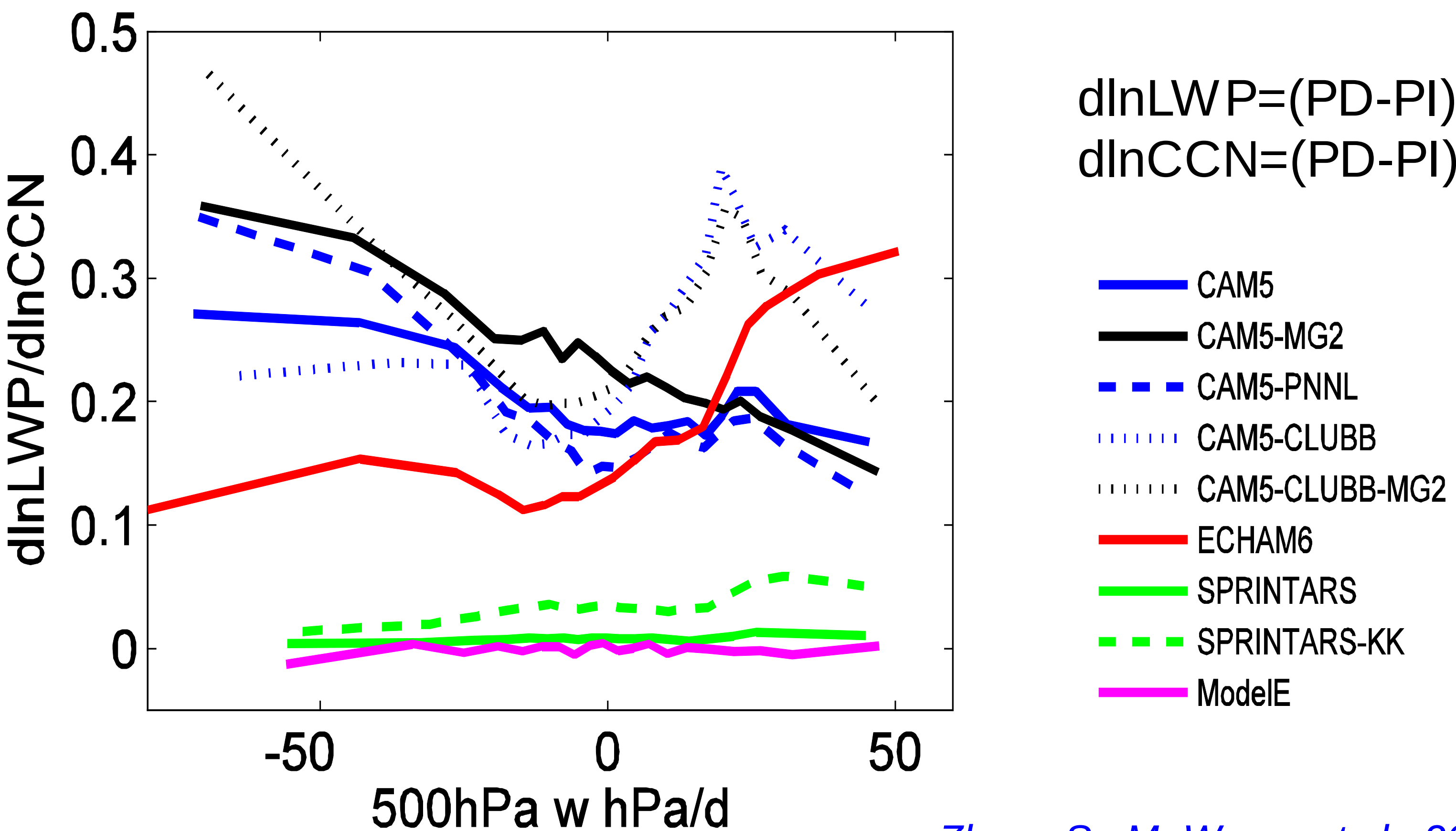
Regime dependence of cloud lifetime effects (as a function of w500)



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

Zhang S., M. Wang, et al., 2016, ACP

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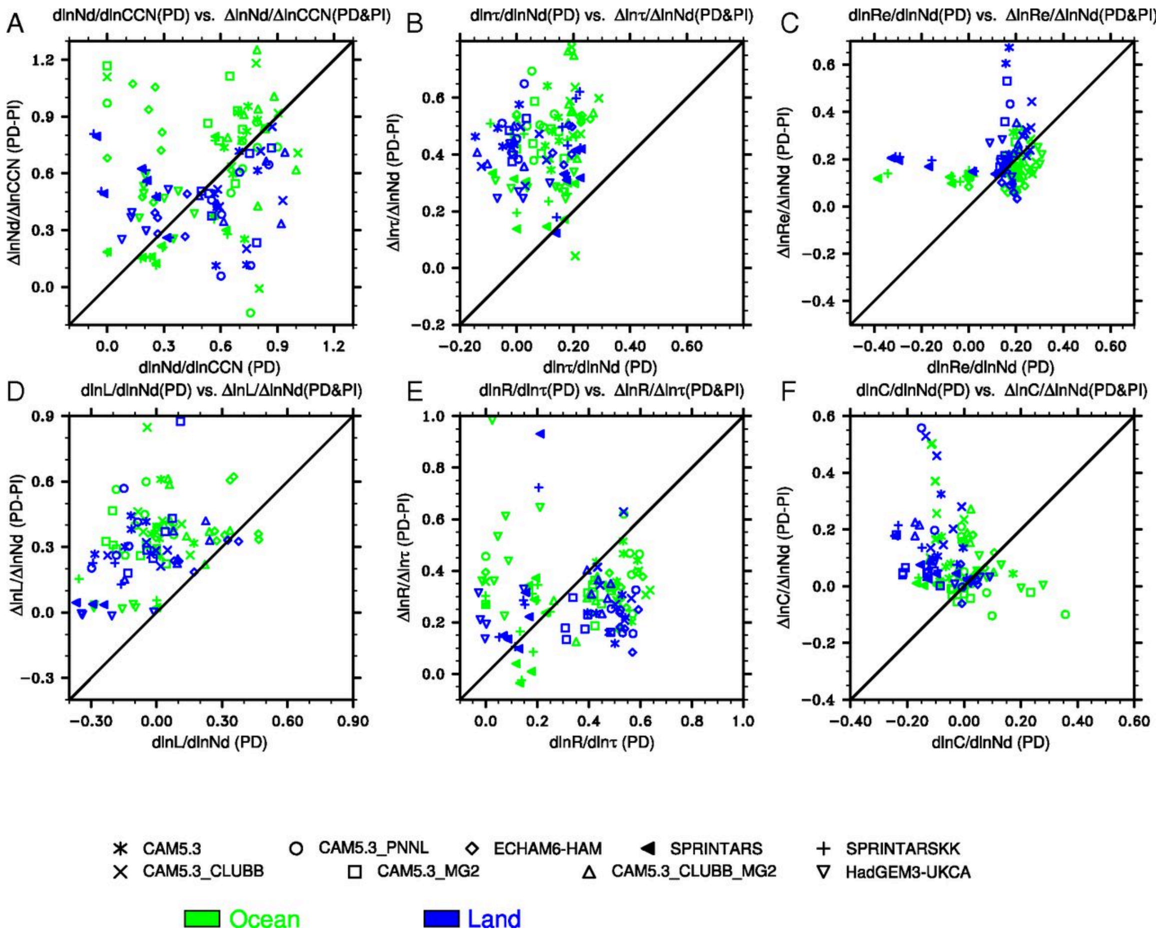
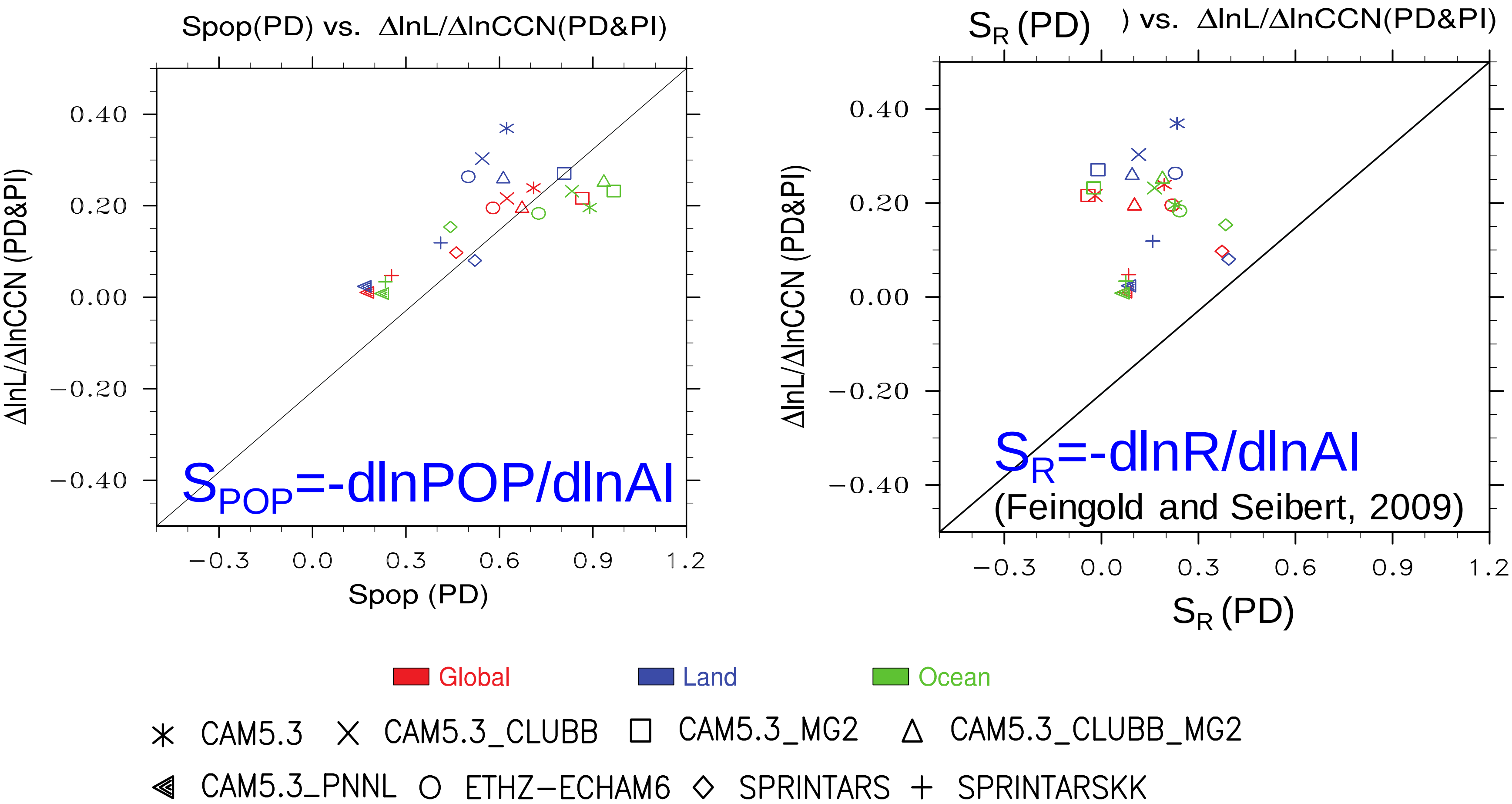
Emergent constraints for other changes?

$$\frac{d\ln\overline{R}}{d\ln\overline{E}}=\left[\frac{d\ln\overline{C}}{d\ln\overline{N}_d}+\frac{d\ln\overline{R}_c}{d\ln\overline{\tau}}\left(\frac{d\ln\overline{L}}{d\ln\overline{N}_d}-\frac{d\ln\overline{r}_e}{d\ln\overline{N}_d}\right)\right]\frac{d\ln\overline{N}_d}{d\ln\overline{CCN}}\frac{d\ln\overline{CCN}}{d\ln\overline{E}}.$$



Ghan, Wang M., et al., 2016@PNAS

S_{POP}: a better metric for constraining cloud water response to aerosols than S_R



S_{POP}: rain frequency susceptibility

S_R: rain susceptibility

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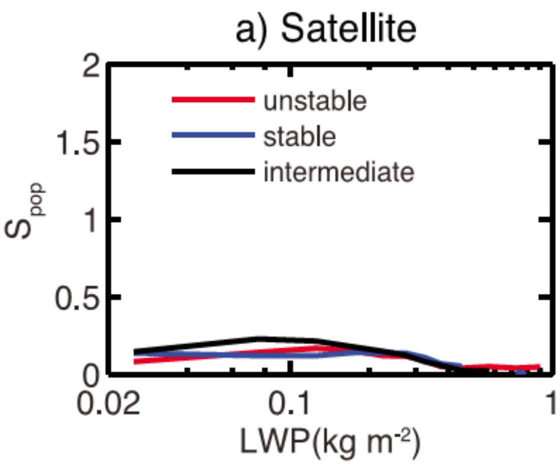
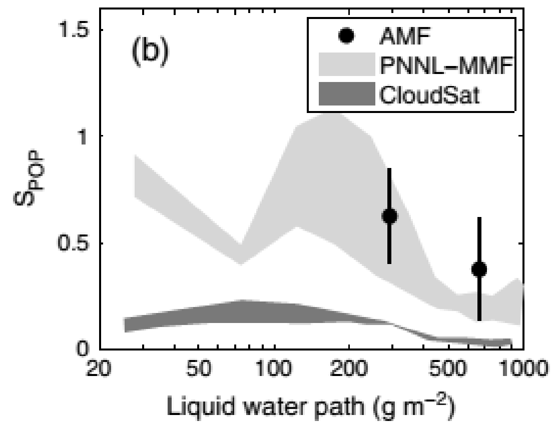
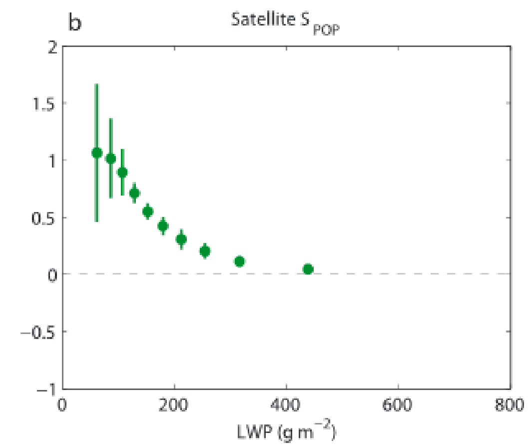
Discrepancy in observational estimates of S_{POP}



Wang et al., 2012,GRL



Mann et al., 2014,JGR



Terai et al., 2015,JGR

$$S_{POP\_AI} = -\frac{d\ln POP}{d\ln AI}$$

$$S_{POP\_CCN} = -\frac{d\ln POP}{d\ln N_{CCN}}$$

$$S_{POP\_CDNC} = -\frac{d\ln POP}{d\ln CDNC}$$

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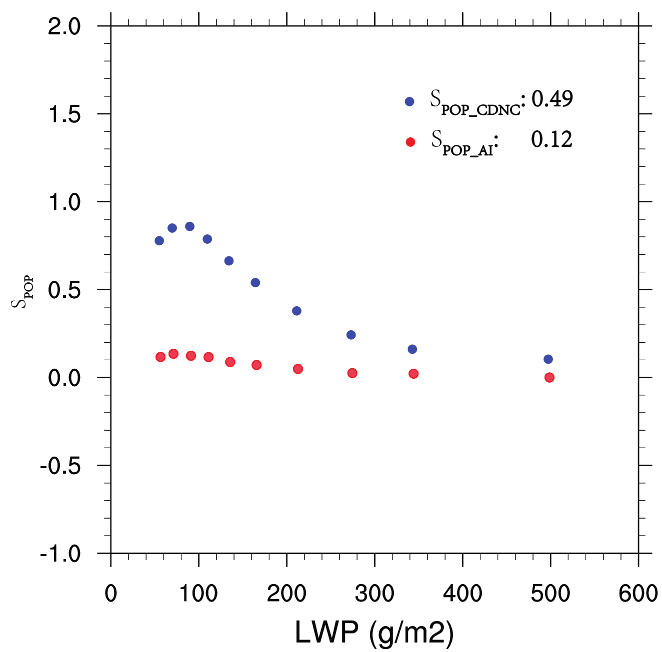
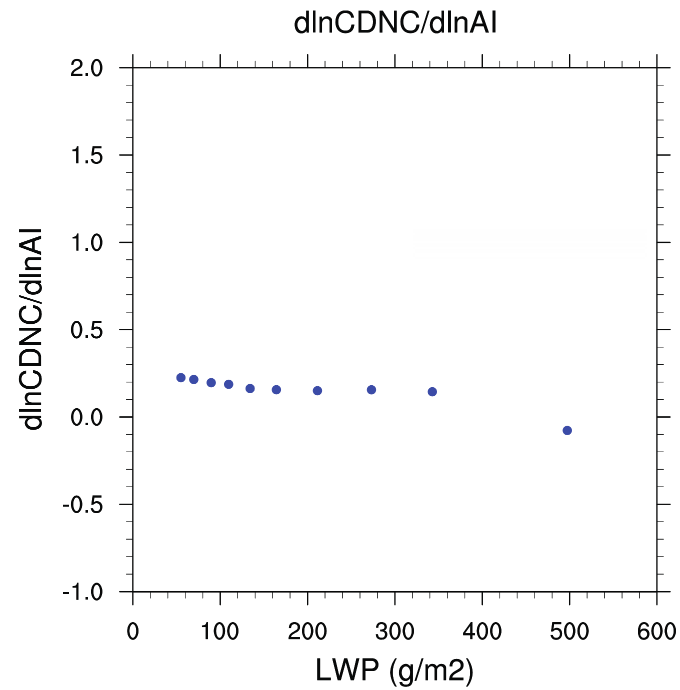
S_{POP_CDNC} vs. S_{POP_AI}





$$S_{POP\_AI} = -\frac{\partial \ln POP}{\partial \ln AI} = -\frac{\partial \ln POP}{\partial \ln CDNC} \bullet \frac{\partial \ln CDNC}{\partial \ln AI} = S_{POP\_CDNC} \bullet \frac{\partial \ln CDNC}{\partial \ln AI}$$

- S_{POP_CDNC} is substantially larger than S_{POP_AI}, which can be explained by the weak dependence of CDNC on AI

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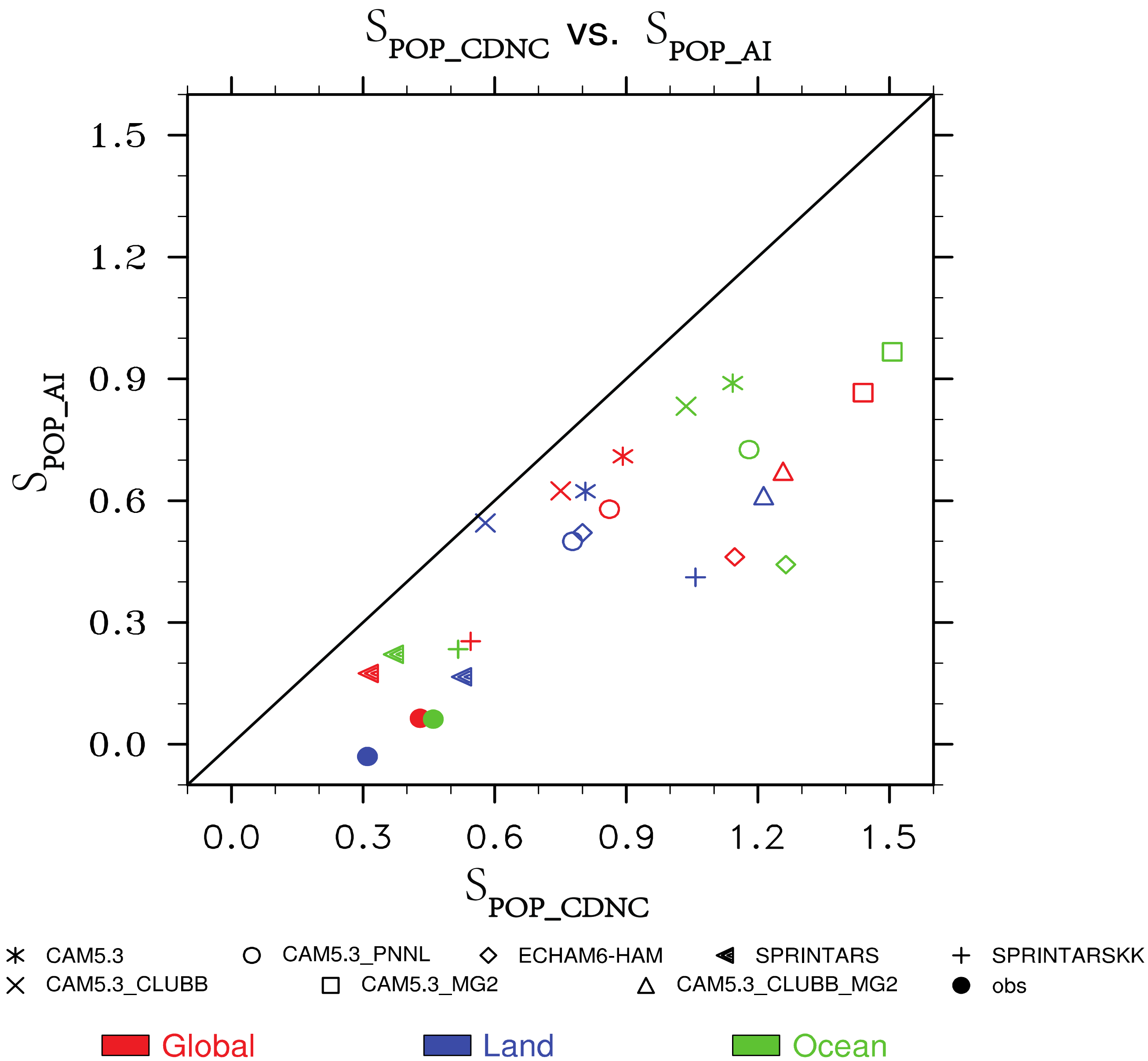
Constraints from both S_{POP_CDNC} and S_{POP_AI}



Summary

- Emergent constraints provides a way to constrain aerosol indirect forcing that is based on physical understanding and interpretation
- Rain frequency susceptibility (S_{POP}) is shown to be a promising emergent constraint for cloud lifetime effects of aerosols
- Further work is need to better quantify observational uncertainties and to develop new emergent constraints on multiple processes for different cloud regimes

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Thanks!

Acknowledgments:

- Nanjing Univ.: S. Zhang, C. Gong, H. Bai, A. Ding, C. Fu
- Pacific Northwest National Laboratory: S. Ghan, M. Ovchinnikov, R. Easter, Y. Qian, W. Gustafson
- Univ. of Wyoming: X. Liu; UMBC: Z. Zhang
- AeroCOM modelers: D. Neubauer, U. Lohmann, S. Ferrachat, T. Takeamura, A. Gettelman, H. Morrison, Y. Lee, D. Shindell, D. Partridge, P. Stier, Z. Kipling

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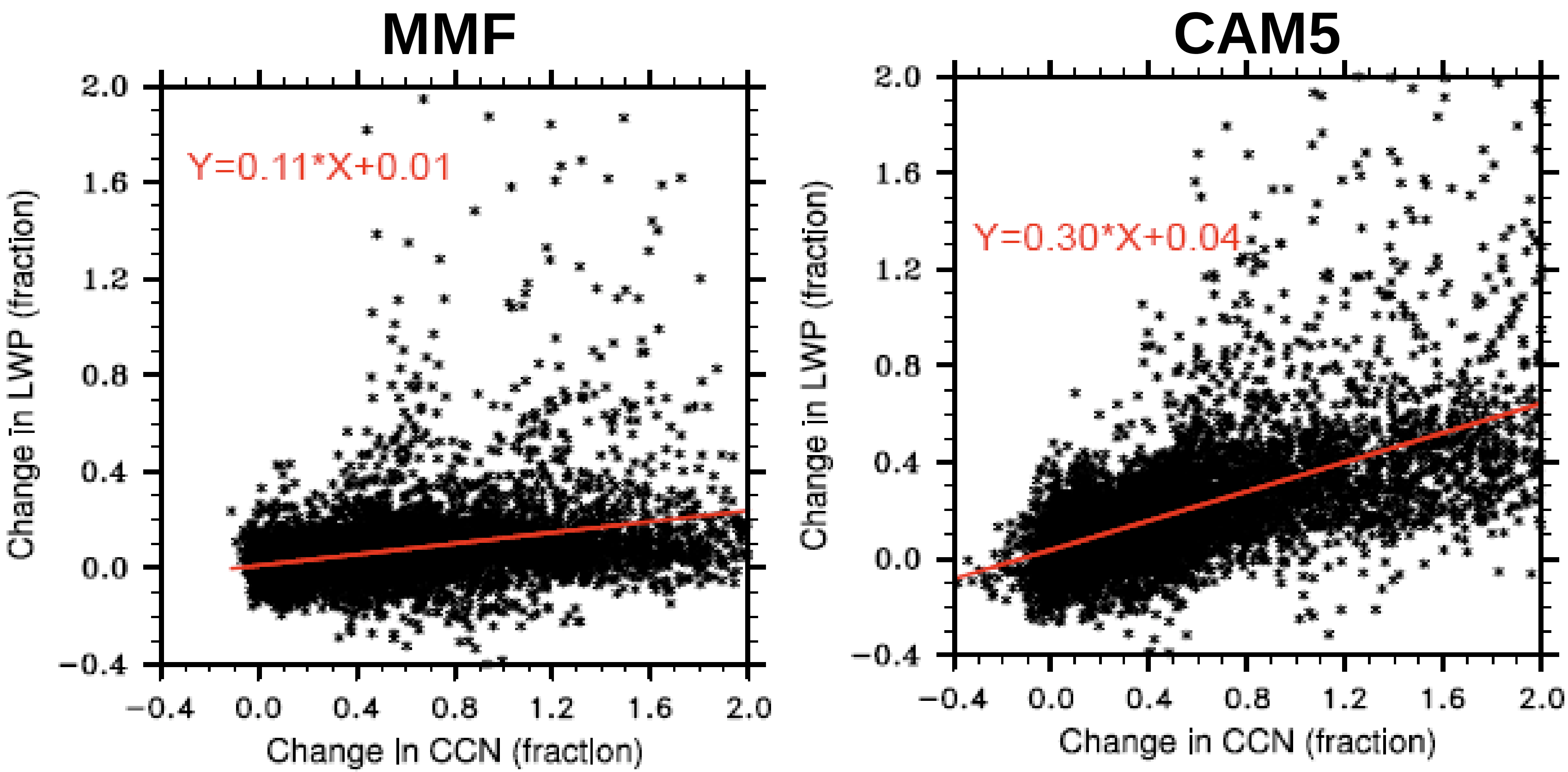
Relative changes in CCN vs. relative changes in LWP: (PD-PI)/PI



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

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A new observable based on NASA A-Train satellites

- Rain frequency susceptibility to aerosol loading

$$S_{pop}=-d\ln POP/d\ln AI$$

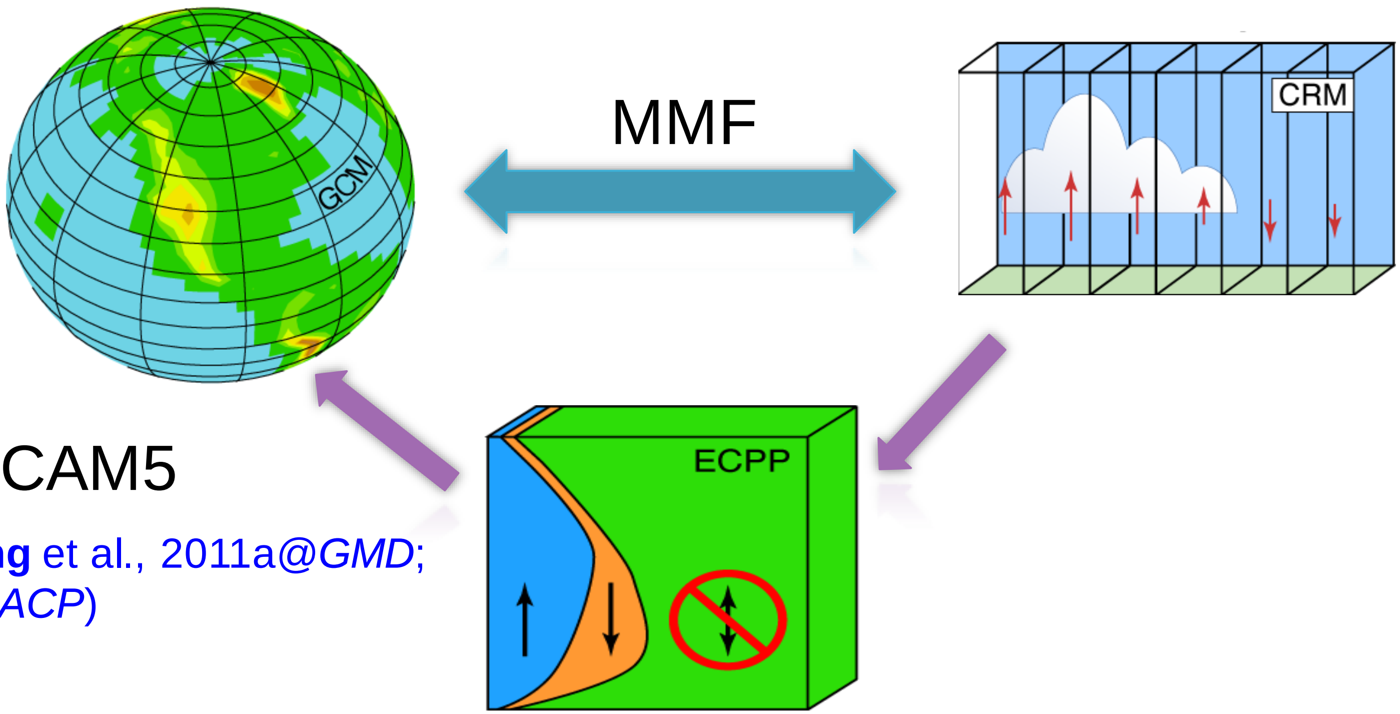
POP: Probability of precipitation （raining clouds divided by all clouds）
AI ： Aerosol Index

- S_{pop} includes information about aerosols, clouds, and precipitation
- S_{pop} is easy to calculate （e.g., S_R, R is rain rate）

The Multi-scale Aerosol-Climate Model

CAM5 with modal aerosols

Two-moment microphysics

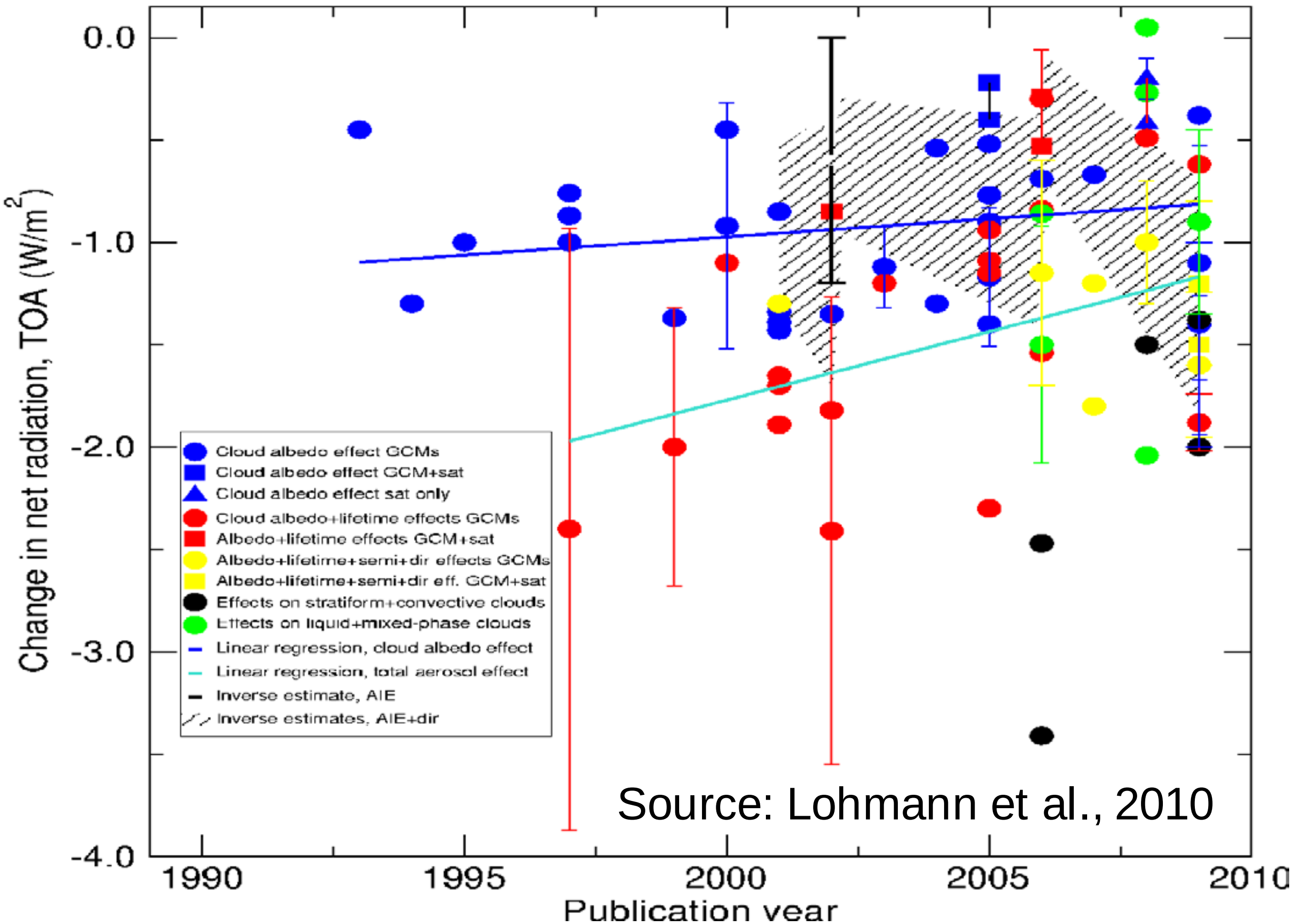


SP-CAM5

(**M. Wang** et al., 2011a@*GMD*; 2011b@*ACP*)

CRM cloud/precipitation statistics used for cloud processing of aerosols

Published estimates of aerosol indirect effects



Source: Lohmann et al., 2010

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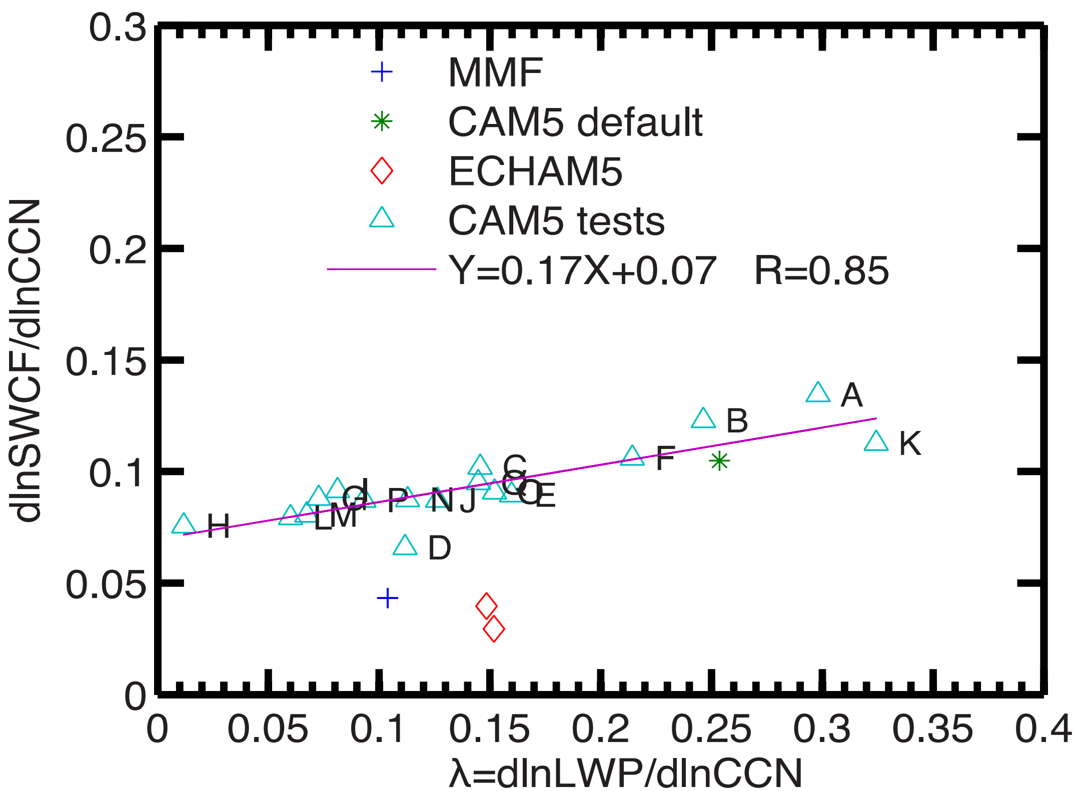
Expressing indirect forcing in terms of liquid water path sensitivity



- Value at λ=0.04 provides estimate of indirect forcing given change in CCN

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