Aerosol Indirect Effect in NCAR CAM: Sensitivity to Aerosol-Cloud Parameterizations

X. Liu

(Pacific Northwest National Laboratory)

Collaborators:

X. Shi, S. J. Ghan, R. Easter, P. Rasch (PNNL)

A. Gettelman, H. Morrison (NCAR)

N. Meskhidze, J. Xu (NCSU)

A. Nenes (Georgia Tech)

C. Chuang (LLNL)

SciDAC Scientific Discovery through Advanced Computing

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U.S. DEPARTMENT OF ENERGY

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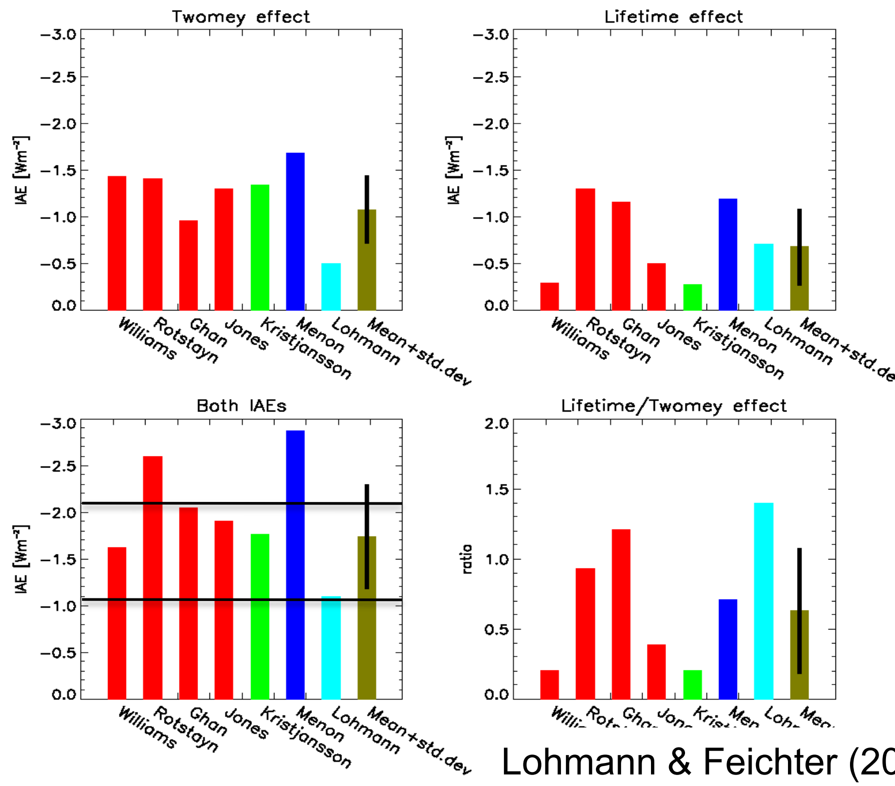
Aerosol Indirect Effect (AIE) in Climate Models

Uncertainties in AIE from

- *Meteorology* (wind, precip, convection, etc.)
- *Aerosol representation* (bulk, modal, sectional, moment)
- *Aerosol treatment* (nucleation, wet removal, etc.)
- *Aerosol emission* (biomass burning, VOC, dust and sea salt)



Lohmann & Feichter (2005)

- Aerosol-cloud interactions:
  - *cloud droplet nucleation* (activation of hygroscopic aerosol particles)
  - *ice crystal formation* (homogeneous & heterogeneous nucleation of aerosols)
  - *precipitation formation*
    - *autoconversion* (collision and coalescience of droplets)
    - *accretion* (collection of droplets by precipitation)

Benchmark 7-Mode Modal Aerosol Model (MAM)

Aitken
number
sulfate
ammmonium
secondary OM
sea salt

Accumulation
number
sulfate
ammonium
secondary OM
hydrophobic OM
BC
sea salt

Fine Soil Dust
number
soil dust
sulfate
ammonium

Fine Sea Salt
number
sea salt
sulfate
ammonium

coagulation
condensation

Primary Carbon
number
hydrophobic OM
BC

Coarse Soil Dust
number
soil dust
sulfate
ammonium

Coarse Sea Salt
number
sea salt
sulfate
ammonium

All modes log-normal with prescribed width.

Total transported aerosol tracers: 31

Cloud-borne aerosol and aerosol water predicted but not transported.

Computer time is ~100% higher than bulk

Simplified 3-mode version of MAM

Assume primary carbon is internally mixed with secondary aerosol.
Neglect aerosol water transport.
Assume ammonium neutralizes sulfate.

Aitken
number
sulfate
secondary OM
sea salt

→ coagulation
condensation

Accumulation
number
sulfate
secondary OM
primary OM
black carbon
soil dust
sea salt

Coarse
number
soil dust
sea salt
sulfate

Total transported aerosol tracers: 15

Computer time is 30% higher than bulk

New Aerosol Processes

- New particle formation (in UT and BL)
- Coagulation within, between modes
- Dynamic condensation of trace gas (H2SO4, NH3) on aerosols
- Aging of primary carbon to accumulation mode based on sulfate coating from condensation & coagulation
- Ultrafine sea salt emissions from Martensson et al.
- A new secondary organic aerosol treatment: reversible condensation of SOA (gas)
- Aerosol optics from Ghan and Zaveri (JGR 2007)

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CAM Cloud Microphysics & Aerosol-Cloud Interactions

- Two-moment scheme (Morrison-Gettelman)
  - Predicts water/ice mixing ratio & number concentrations
  - Gamma functions, simplified (m=0) for ice
  - 2-moment treatment extends to diagnostic precipitation
- Bergeron processes determine liquid/ice partition
  - Vapor deposition, heterogeneous freezing
  - Ice super-saturation allowed
- Droplet nucleation on aerosol (Abdul-Razzak & Ghan)
- Ice nucleation on aerosols (Liu et al 2007)
  - Ice assumed to be spherical (fall speed & radiation)
- Consistent treatment of sub-grid cloud water for all relevant microphysics processes
- Consistent treatment of size distribution in radiation
  - Shape parameters (g) describe look up table for cloud drops

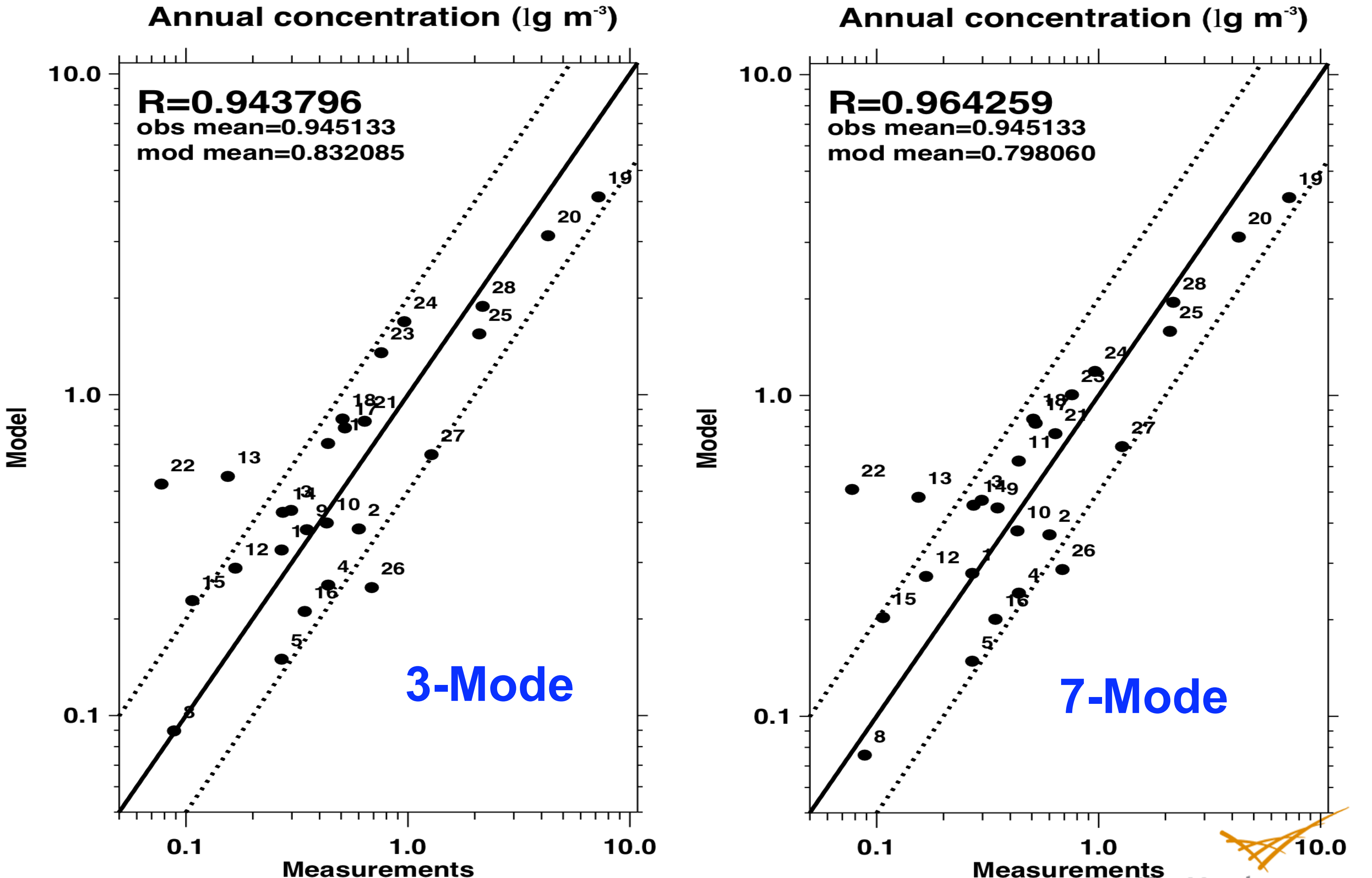
CAM Simulations (camdev23_CAM3.6.28)

- MAM 3-mode version
- 5 years at 1.9°x2.5° resolution, PD and PI

Emissions:

- IPCC AR5 emissions for anthr. OM, BC, SO2, SO4
- AEROCOM emissions for natural DMS, SO2, SO4, injection heights and primary particle sizes
- Biogenic SOA(g) emission: apply yields on MOZART VOCs emissions

SO_4 compared with RSMAS data



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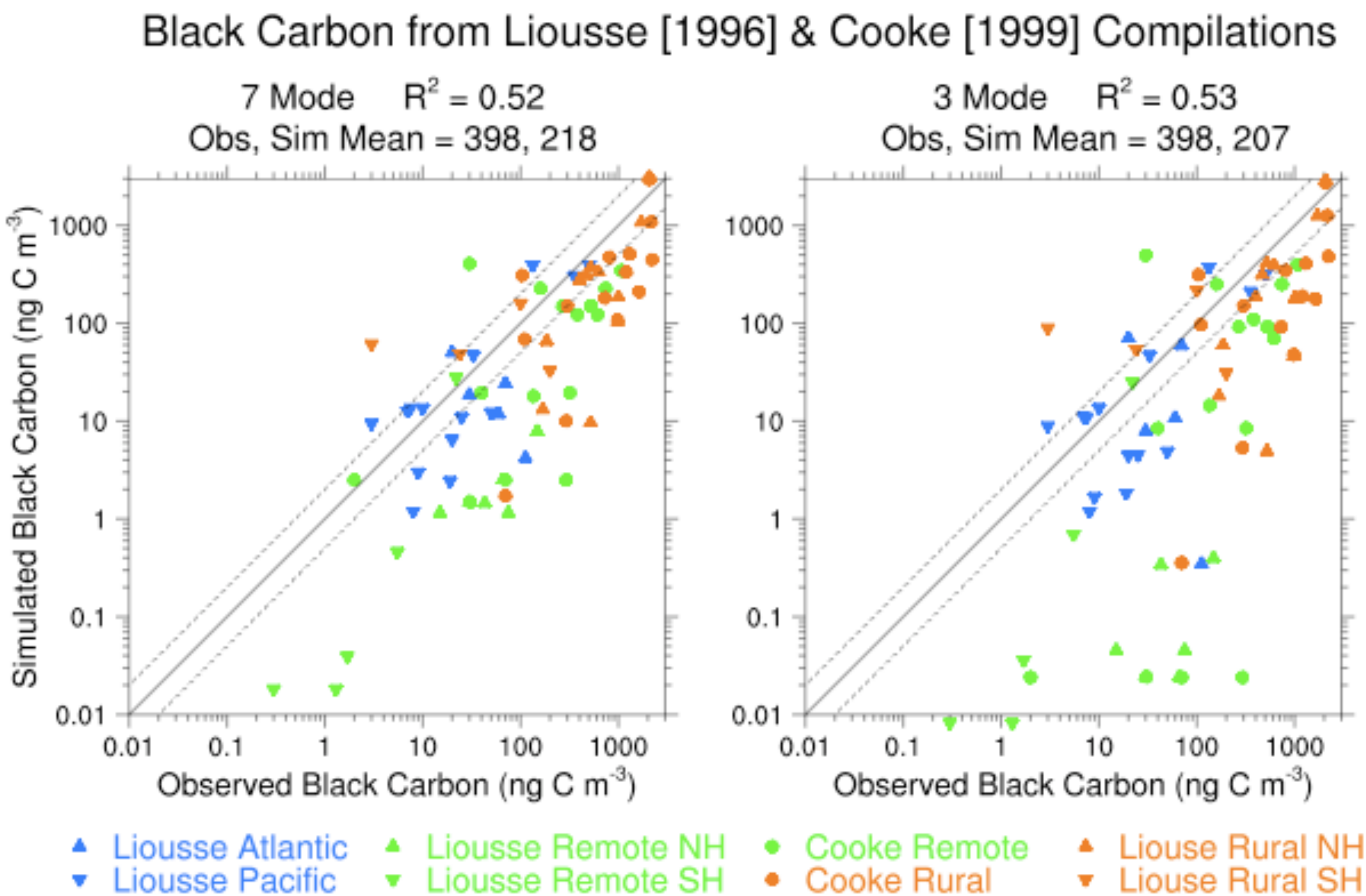
BC compared with global data



7-Mode **3-Mode**

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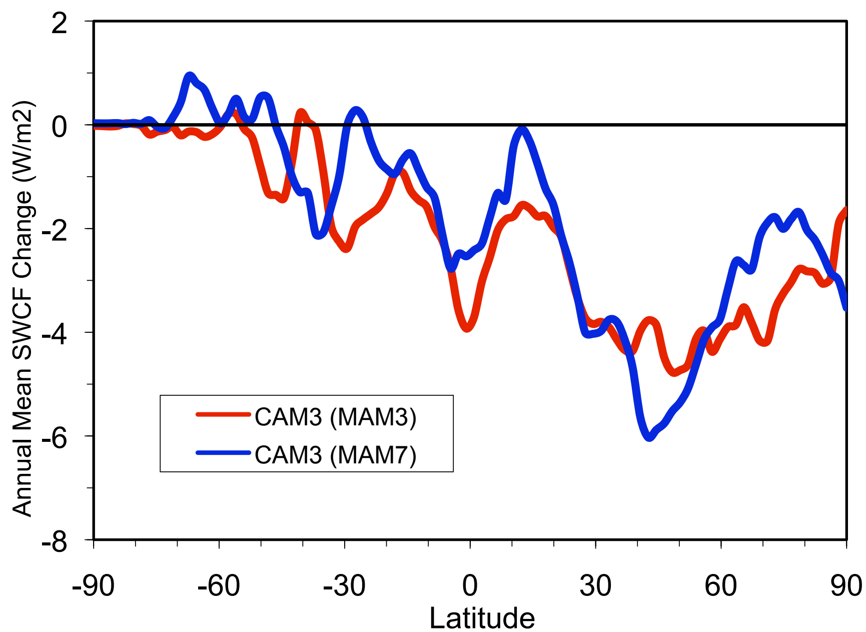
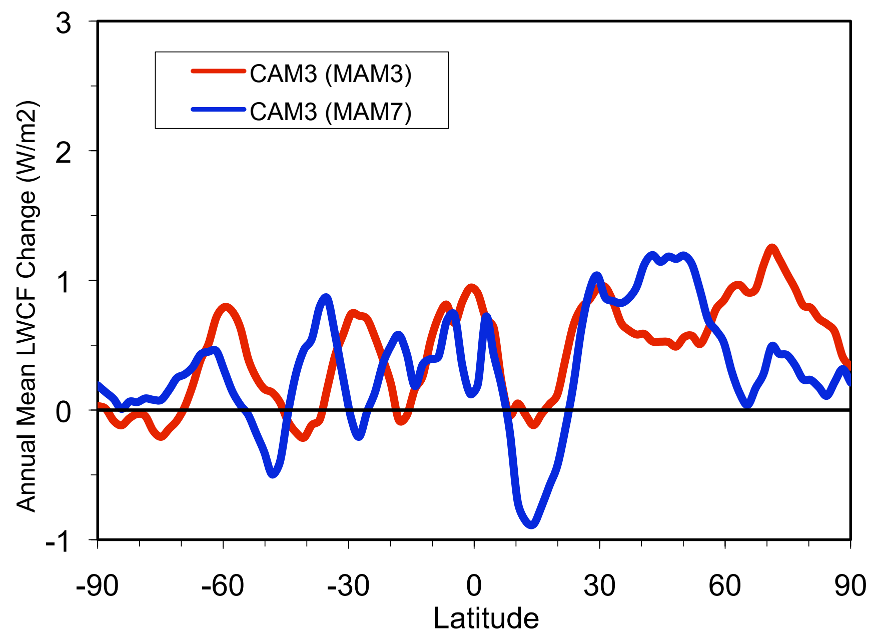
Anthropogenic Indirect Effect (AIE)

Present – Past Shortwave Cloud Forcing (W/m2)



Present – Past Longwave Cloud Forcing (W/m2)



ΔSWCF (W m^{-2}) = -2.2 **= -1.8** **ΔLWCF (W m^{-2}) = +0.5**

Latest version: -1.3

Latest version: +0.4

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Cloud Droplet Activation Schemes

Abdul-Razzak & Ghan (1998; 2000) - mechanistic

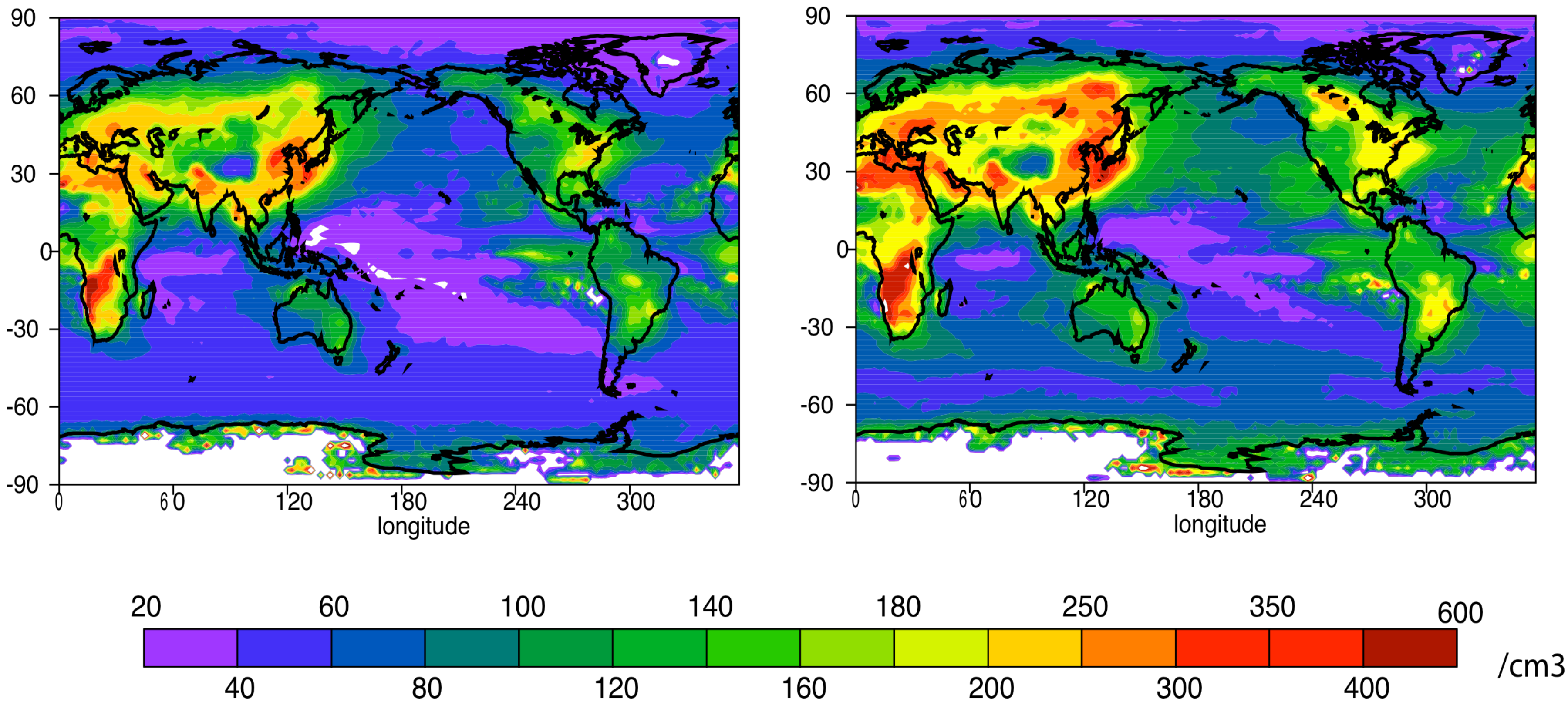
- For lognormal aerosol models
- Fit of parcel model simulation for max supersaturation
- Computationally efficient
- Kinetic limitations of droplet condensation are considered

Fountoukis & Nenes (2005) - mechanistic

- For lognormal aerosol models
- Derived from theoretical consideration
- Computationally efficient (need some iterations, and can be 20-40% more expensive than AR-G depending on mode number.
- Can treat very complex internal/external aerosol, and effects of organic films on droplet growth kinetics.

Cloud Droplet Number Concentration at 820 hPa

Abdul Razzak-Ghan | **Fountoukis-Nenes**



FN produces 20-30% higher CDNC than AR-G on global average

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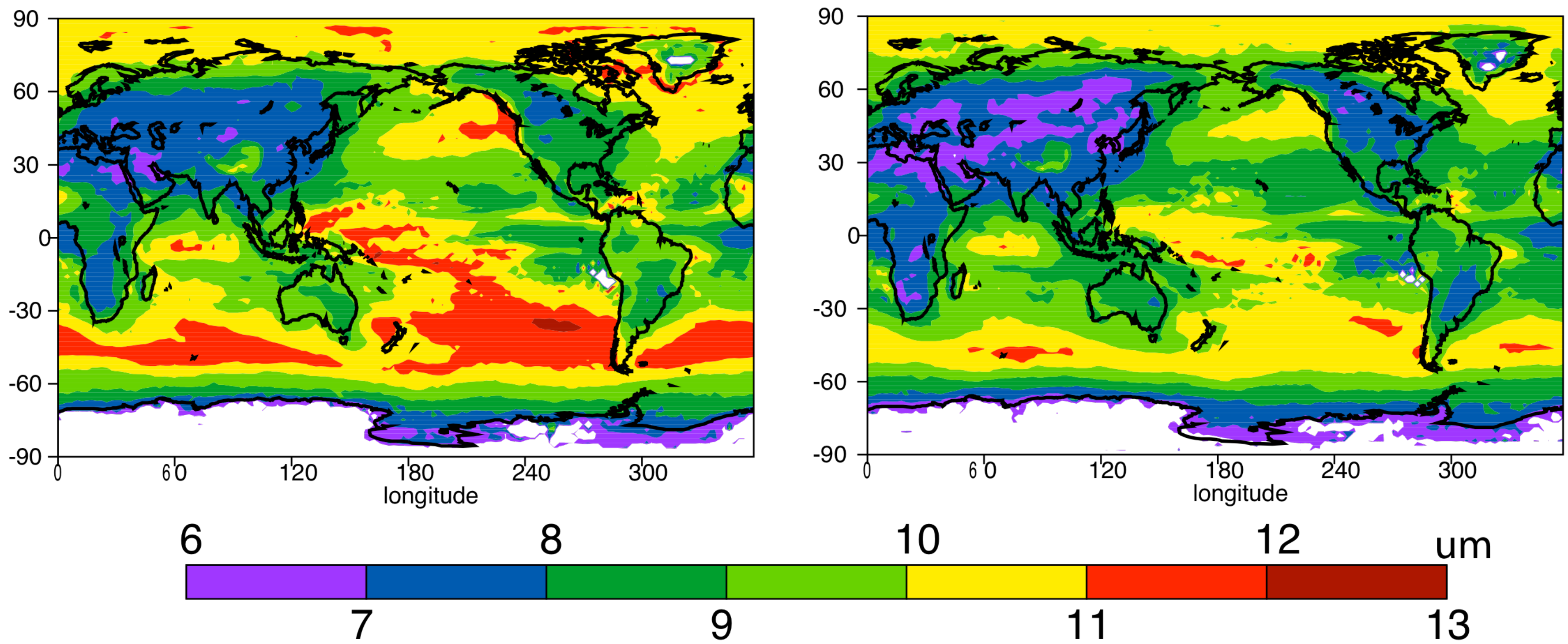
Cloud Droplet Effective Radius at 820 hPa

Abdul Razzak-Ghan | **Fountoukis-Nenes**



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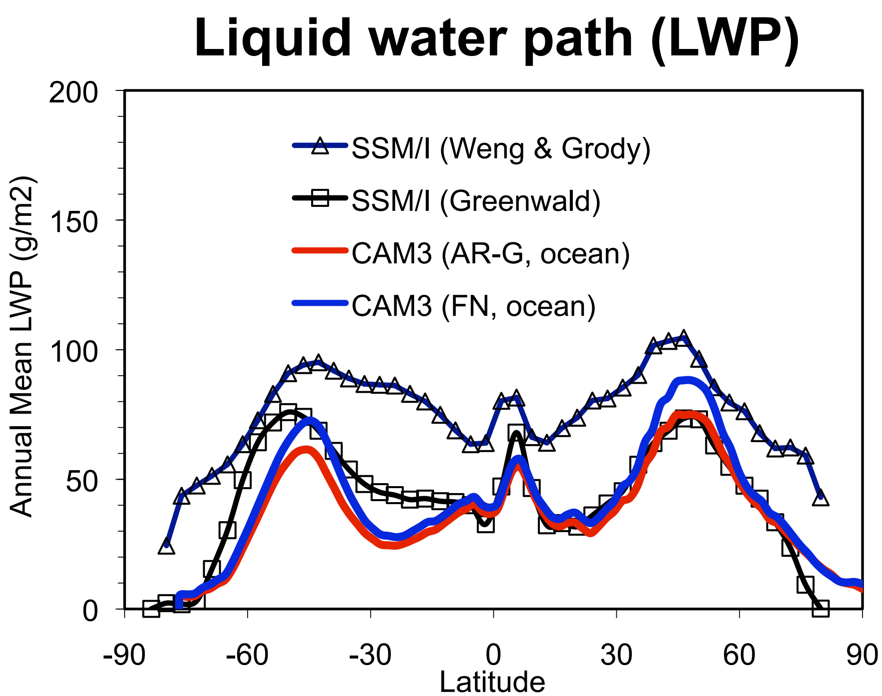
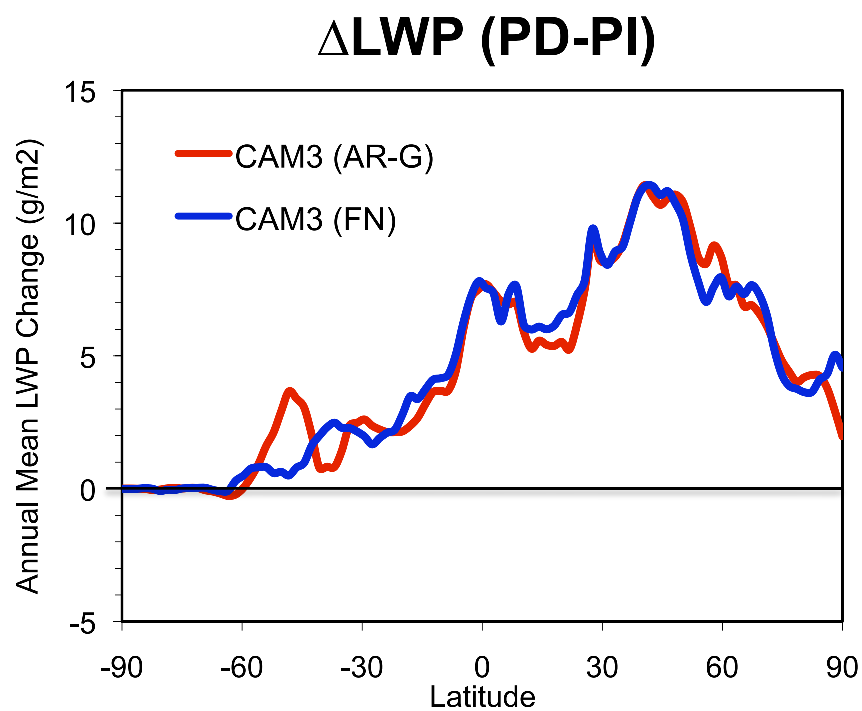
LWP Sensitivity to Droplet Activation Scheme





LWP (g/m2) = 41 (AR-G); 46 (FN)
ΔLWP(g/m^2) = +5.1 (AR-G); +5.2 (FN)

Same autoconversion scheme (KK)

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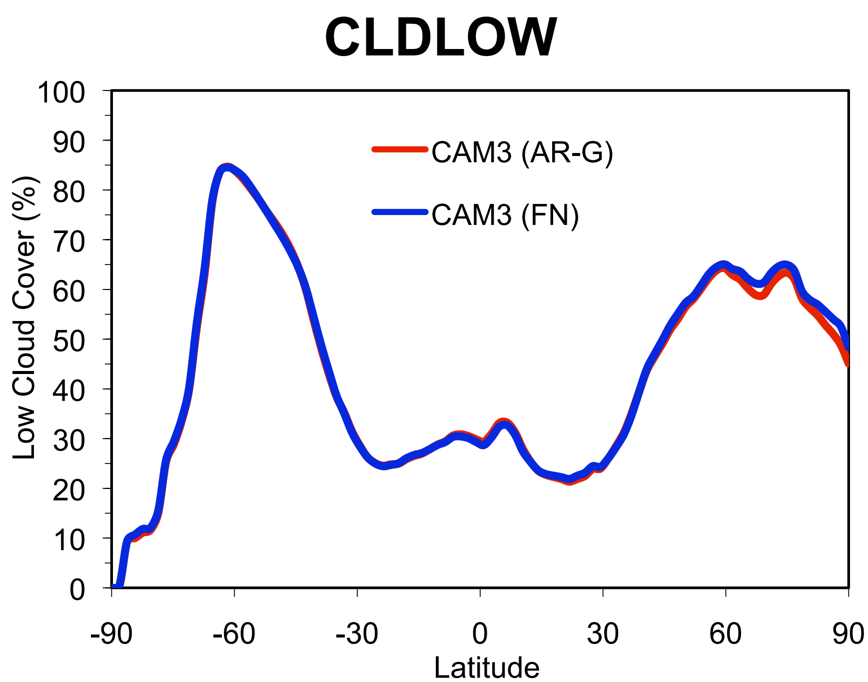
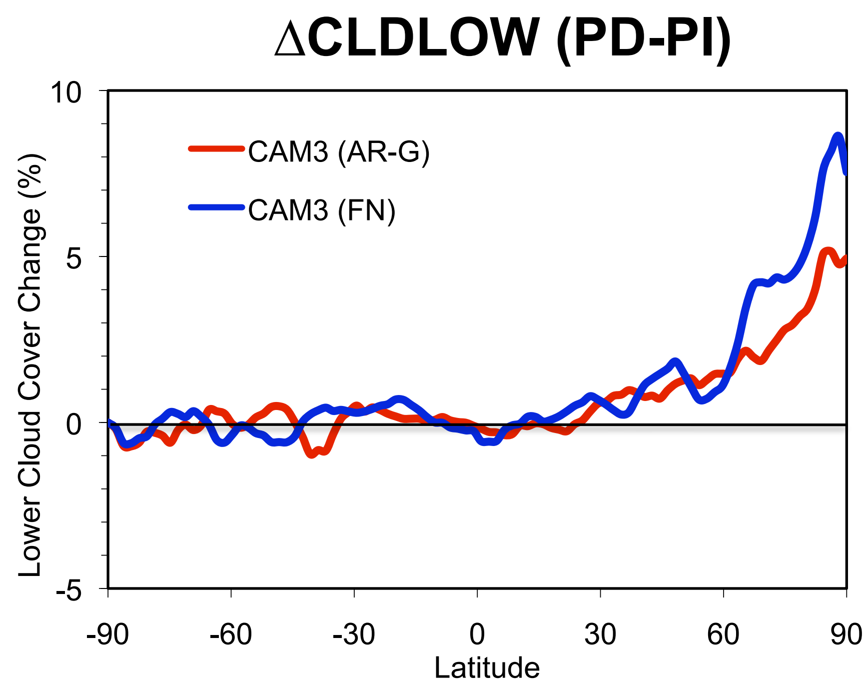
Low-Cloud Cover Sensitivity to Droplet Activation Scheme





CLDLOW (%) = 40.0 (AR-G); 40.2 (FN)
ΔCLDLOW(%) = +0.3 (AR-G); +0.5 (FN)

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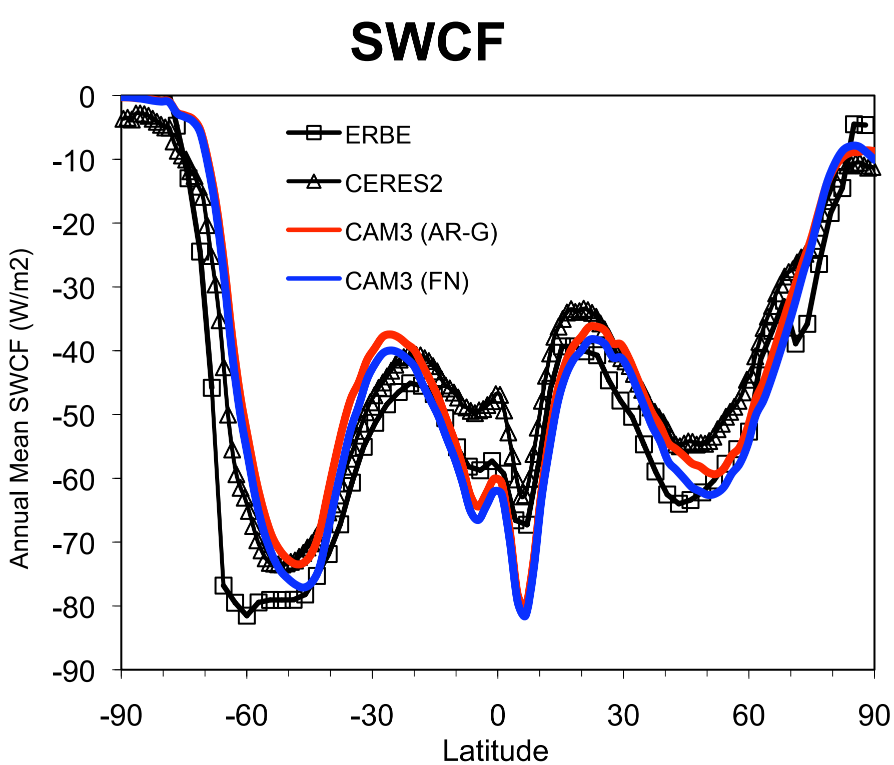
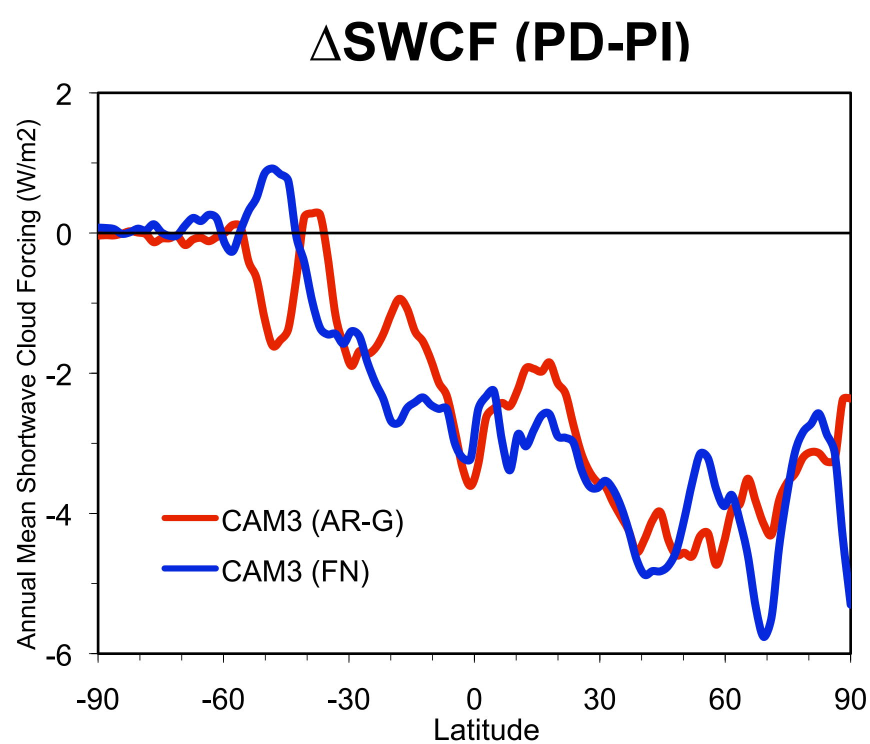
SWCF Sensitivity to Droplet Activation Scheme





SWCF (W/m^2) = -50 (AR-G); -52 (FN)
ΔSWCF(W/m^2) = -2.2 (AR-G); -2.4 (FN)

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Autoconversion Schemes

Beheng (1994)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 6\times10^{25}\, n^{-1.7}\, \rho_a^{3.7}\, N_c^{-3.3}\, q_l^{4.7}$$

Khairoutdinov-Kogan (2000, CAM3 MG)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 1350\ q_l^{2.47}\, N_c^{-1.79}$$

Liu-Daum (2004)

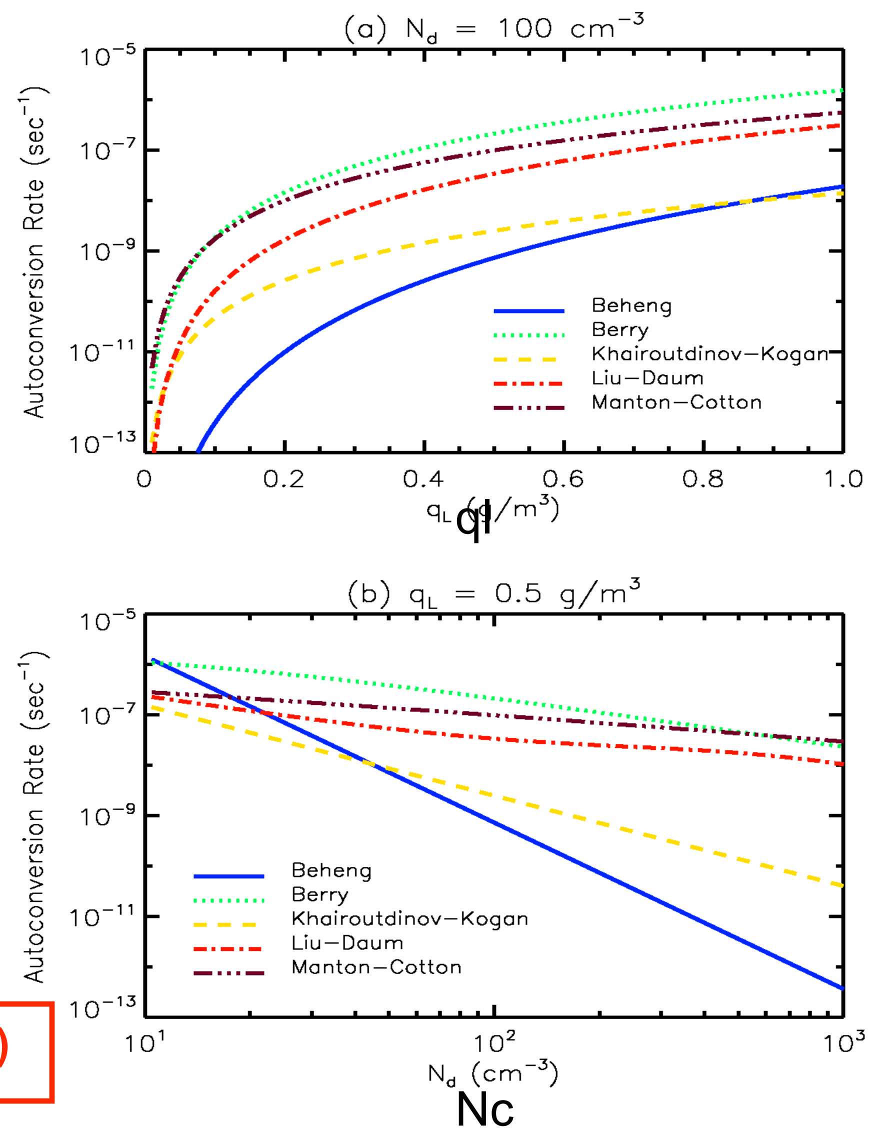
$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = \kappa_2 \left(\frac{3\,\rho_a}{4\,\pi\,\rho_w}\right)^2 \beta_6^6\, \frac{q_l^3}{N_c}\, \mathrm{H}(R_6 - R_{6c})$$

Manton-Cotton (1977, CAM3 Default)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = C_{l,aut}\ q_l^2\, \frac{\rho_a}{\rho_w} \left(\frac{q_l\,\rho_a}{\rho_w\, N_c}\right)^{1/3} \mathrm{H}(r_{3l} - r_{3lc})$$

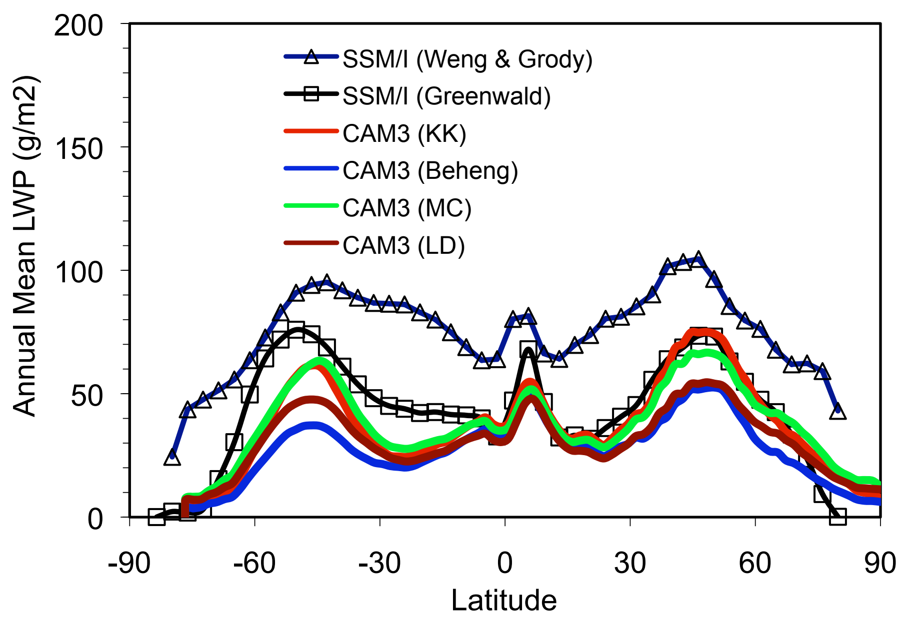
Auto. rate ~ $N_c^{(-3.3,\ -1.79,\ -1.0,\ -0.33)}$

Autoconversion Rate f(ql, Nc)

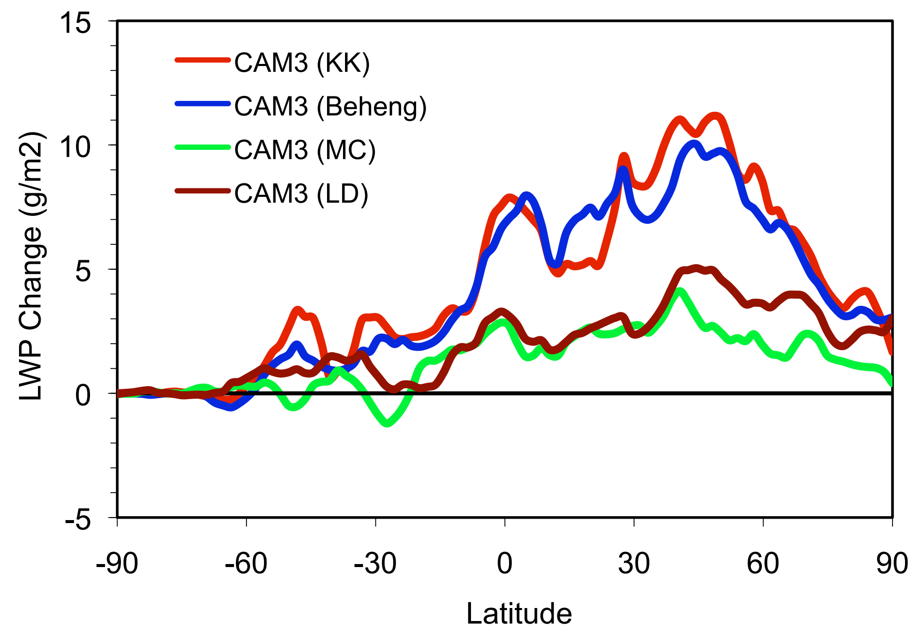


LWP Sensitivity to Autoconversion Schemes

LWP

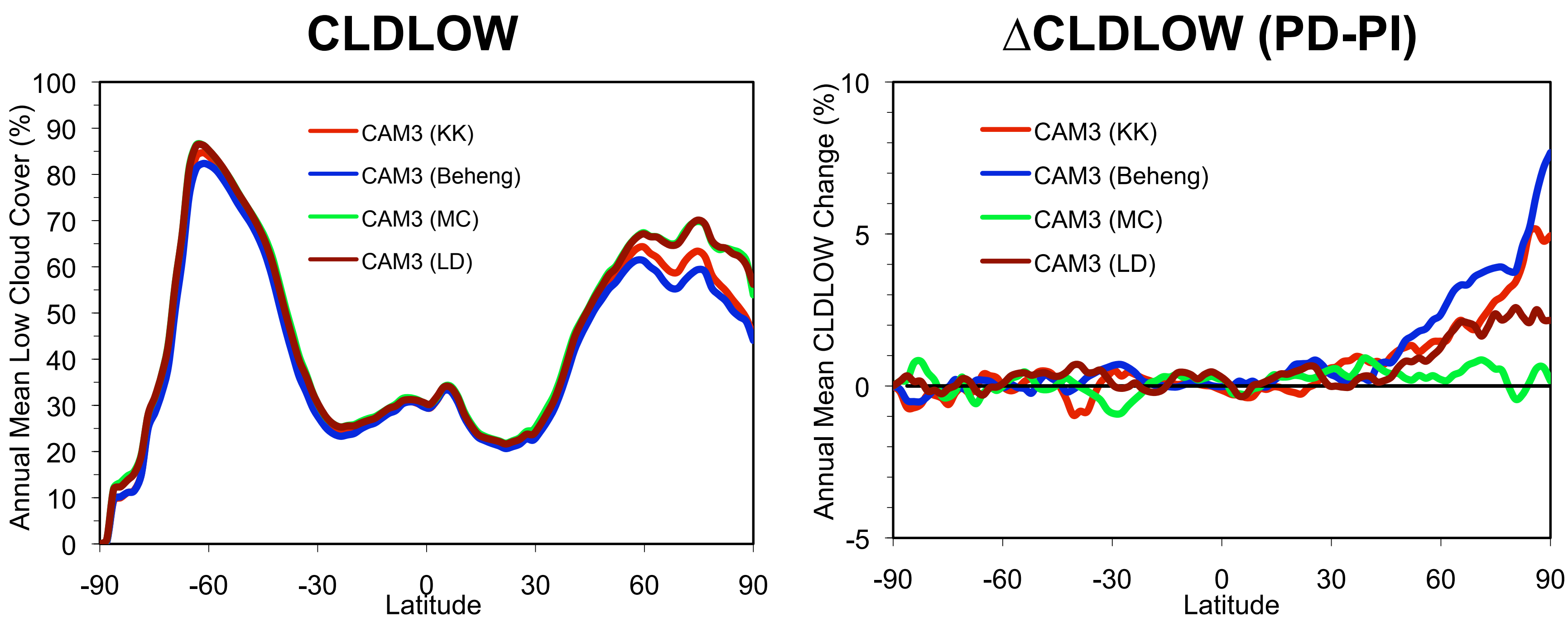


ΔLWP (PD-PI)



LWP (g/m2) = 40 (KK); 31 (BH); 38 (MC); 32 (LD)
ΔLWP(g/m^2) = 5.0 (KK); 5.0 (BH); 1.0 (MC); 2.0 (LD)

Low-Cloud Cover Sensitivity to Autoconversion Schemes



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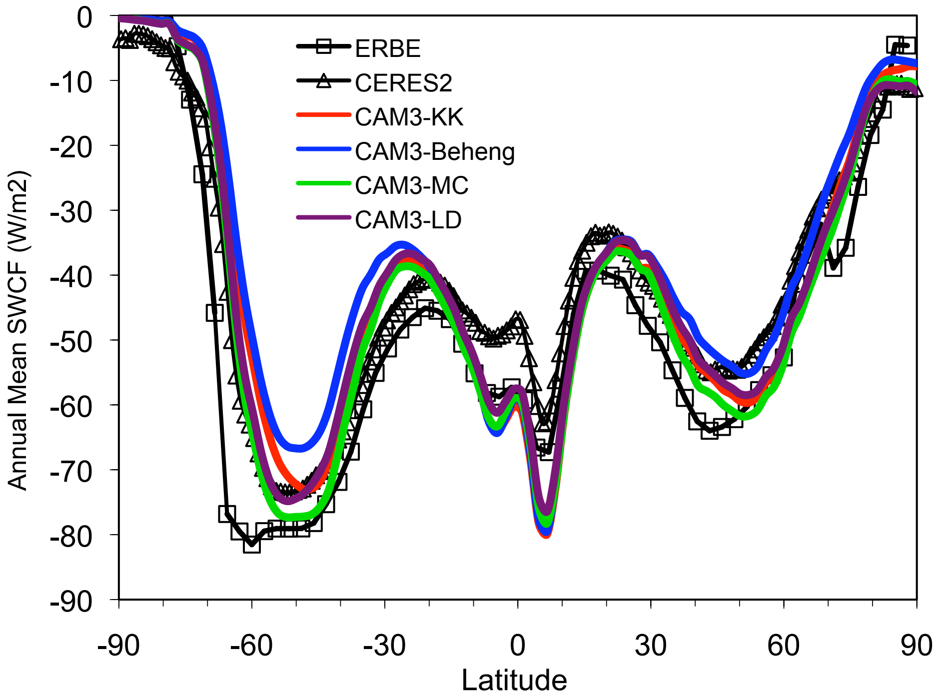
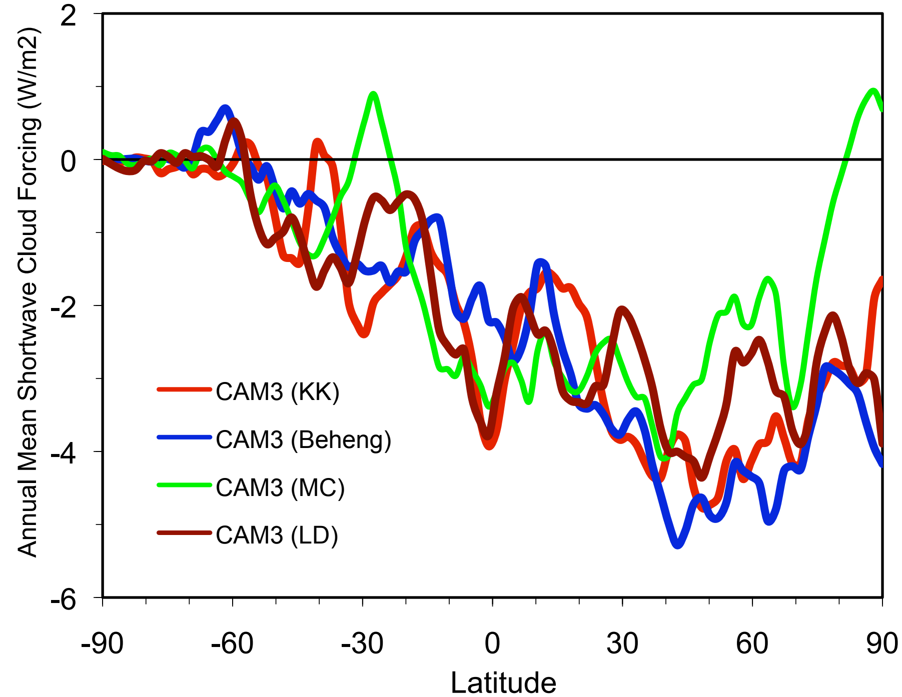
SWCF Sensitivity to Autoconversion Schemes

SWCF



ΔSWCF (PD-PI)



SWCF (W/m2) = -49 (KK); -47 (BH); -51 (MC); -49 (LD)
ΔSWCF (W/m^2) = -2.2 (KK); -2.2 (BH); -1.9 (MC); -2.1 (LD)

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Summary

- Different cloud droplet activation schemes lead to a change in LWP by 10 g/m2 and SWCF by 5 W/m2 in the storm track regions.
  - Anthropogenic AIE (cloud forcing change) ranges from -1.7 to -1.9 W/m2 on the global mean;

- Different auto-conversion schemes lead to a change in LWP by 30 g/m2 and SWCF by 10 W/m2 in the storm track regions.
  - Anthropogenic AIE ranges from -1.5 to -1.8 W/m2 on the global mean;

We don't find strong sensitivities of AIE to droplet activation schemes and autoconversion schemes!