Lawrence Livermore National Laboratory

Sensitivity of Aerosol Indirect Effects to Cloud Parameterizations in Short-Range Weather Forecasts with CAM3

Over the Southern Great Plains during May 2003 IOP

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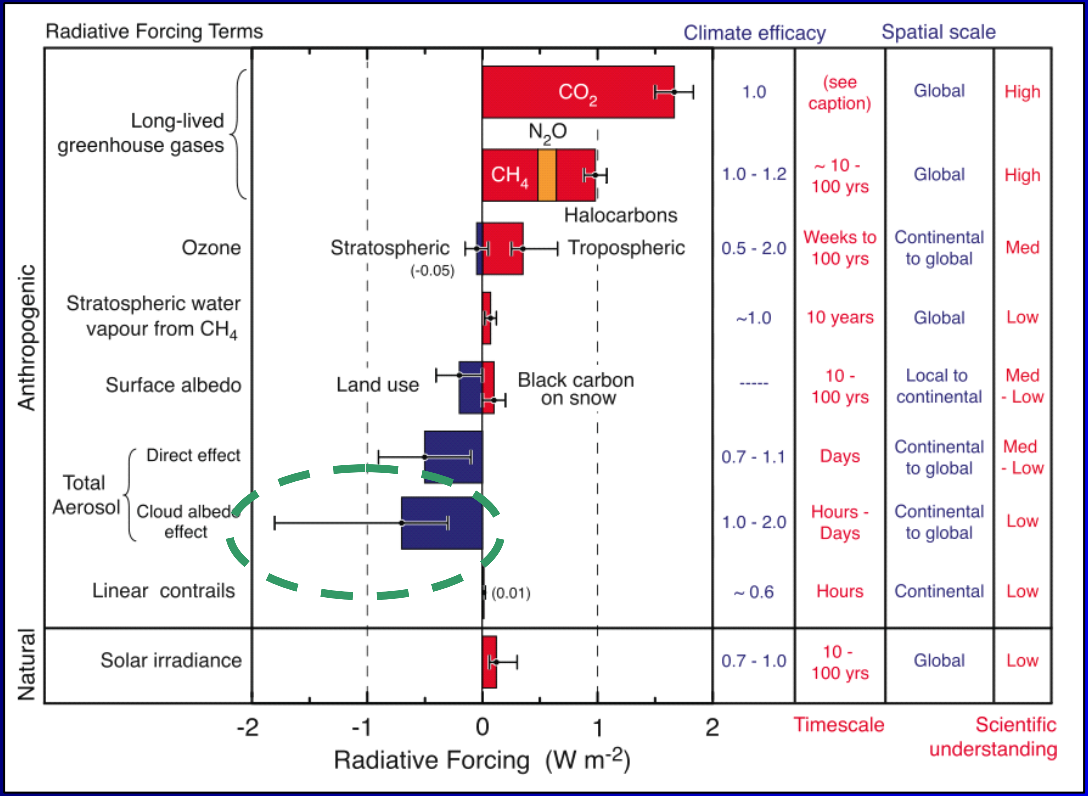
Why are aerosol/cloud interactions important?

- The greatest uncertainty in the assessment of radiative forcing arises from the interactions of aerosols with clouds.

Radiative forcing of climate between 1750 and 2005 (IPCC, 2007)

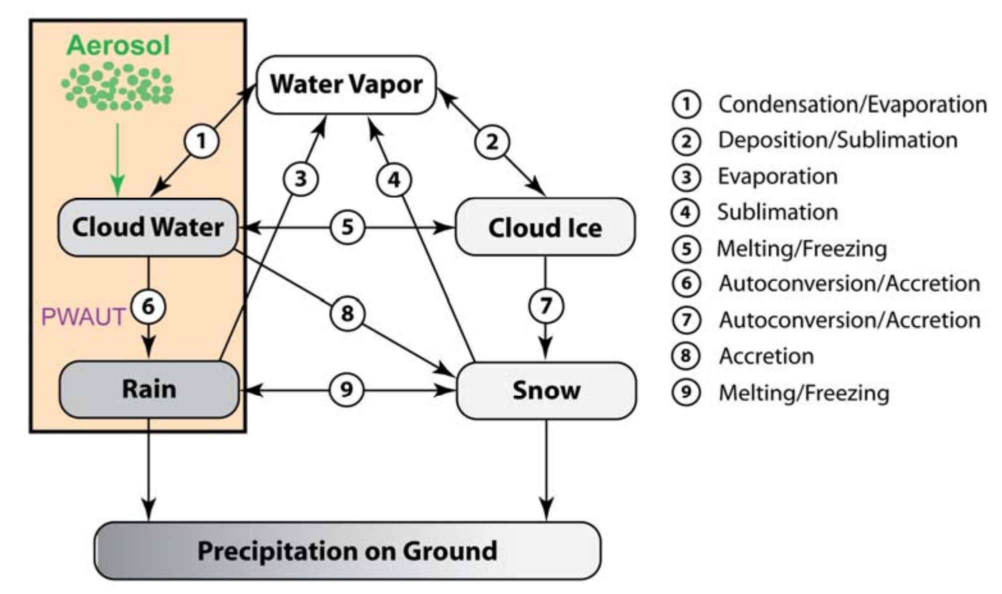


Sources of uncertainty

- Emissions
- Gas to particle conversion
- Aerosol size distribution
- *Linkage between aerosols and clouds*

Treatments of aerosol/cloud interactions in GCMs

Cloud microphysics scheme in CAM3.5 (RK version)



Cloud Drop Nucleation
The process to activates aerosols to form cloud droplets.

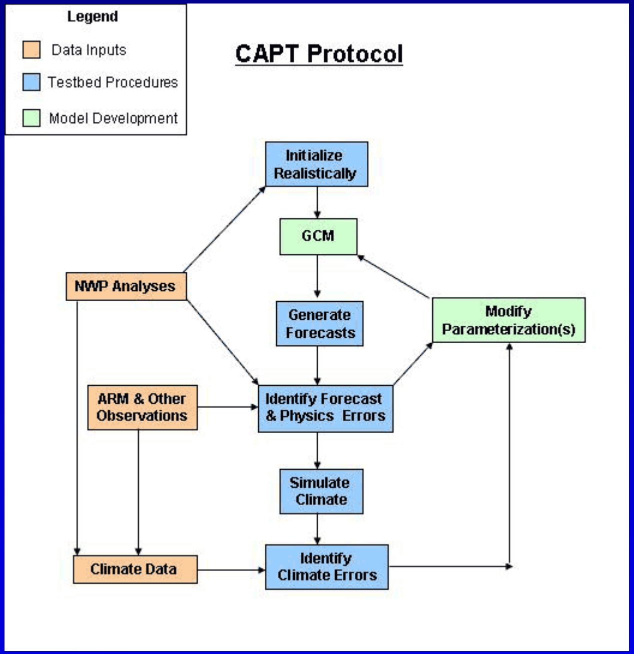
Autoconversion
The process to initiate raindrops by collisions and coalescence of cloud droplets.

Previous studies on the sensitivity of aerosol/cloud interactions to model treatments

- Yearly GCM simulations (Lohmann et al., 2000; Chuang et al., 2002; Rotstayn and Liu, 2005; Penner et al., 2006; …..)
- Daily SCM simulations (Menon et al., 2003; …..)
- Offline calculations (Chen and Penner, 2005; ……)

Methodology of this study

- Under the CAPT framework, CAM3 is run in short-range weather forecasts (~days) initialized by realistic data (i.e., NASA GEOS4).
- The short-range weather forecasts over SGP during May 2003 IOP are evaluated with ARM data.
- Examine the variations of cloud properties and radiative fluxes with different treatments of cloud drop nucleation and autoconversion.
- Assess the sensitivity of aerosol indirect effects.



The CAPT (Climate Change Prediction Program - ARM Parameterization Testbed) is analogous to a common NWP approach for development of forecast models. It is useful for diagnosing parameterization problems that may produce systematic model errors on climate time scales . (Phillips et al., 2004)

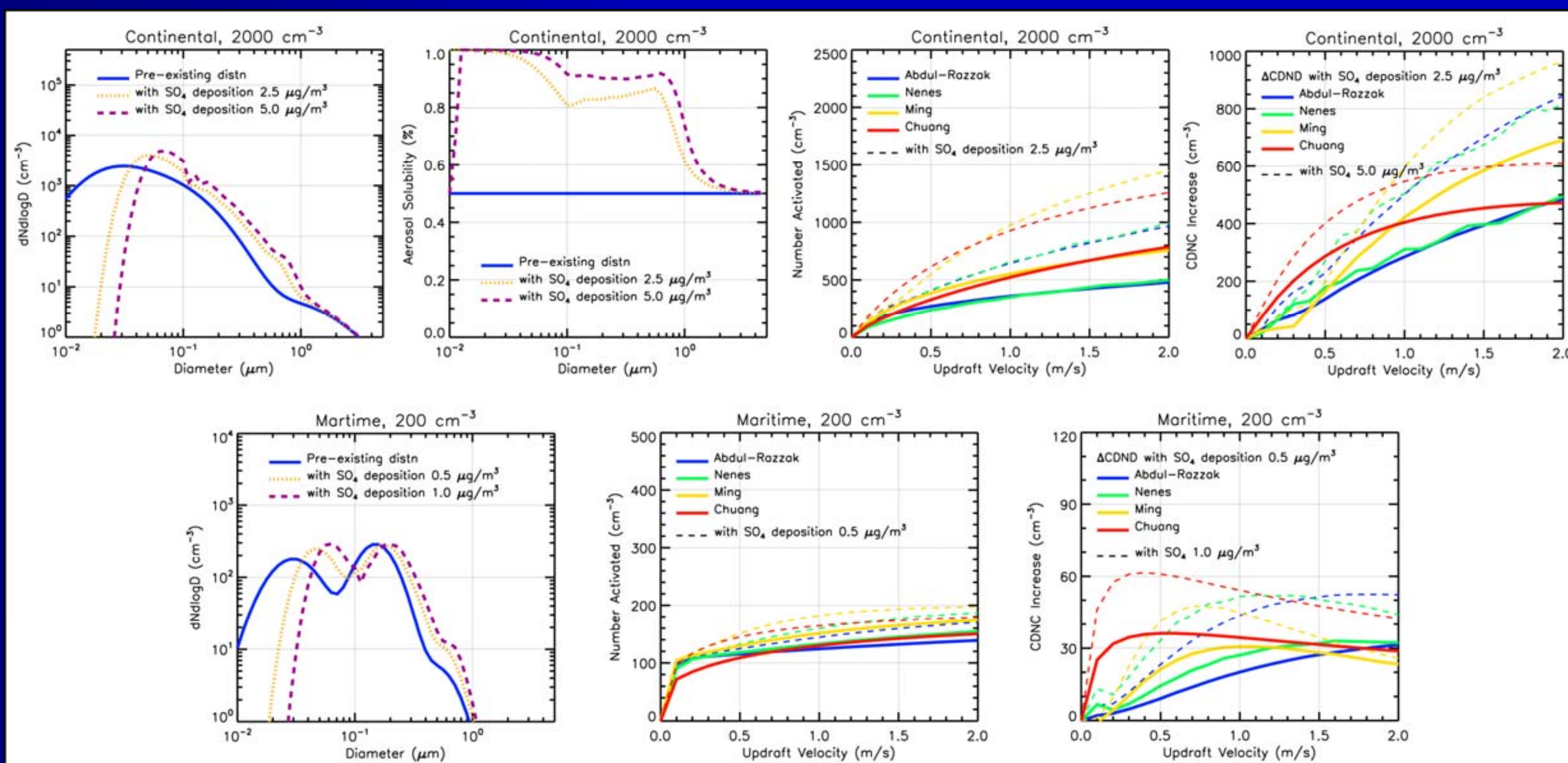
Nucleation parameterizations evaluated in this study

(1) Abdul-Razzak and Ghan, 2002; (2) Nenes and Seinfeld, 2003
(3) Ming et al., 2006; and (4) Chuang et al., 2002

- Internally mixed aerosols. Aerosol size distribution and solubility vary with the deposition of sulfate on pre-existing particles (Chuang et al., 1997, 2002).
- Variations in the increase of Ndrop associated with sulfate among different parameterizations are not necessarily proportional to their differences in Ndrop.

  -- higher Ndrop ≠ higher sulfate indirect forcing

Variations in predicted cloud droplet concentrations



Autoconversion schemes evaluated in this study

Beheng (1994)

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

Berry (1968)

$$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = \frac{\rho_a\, q_l^2}{1.2\times10^{-4} + \dfrac{1.596\times10^{-12}\, N_c}{D_o\, \rho_a\, q_l}}$$

Khairoutdinov-Kogan (2000, CAM3 MG)

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

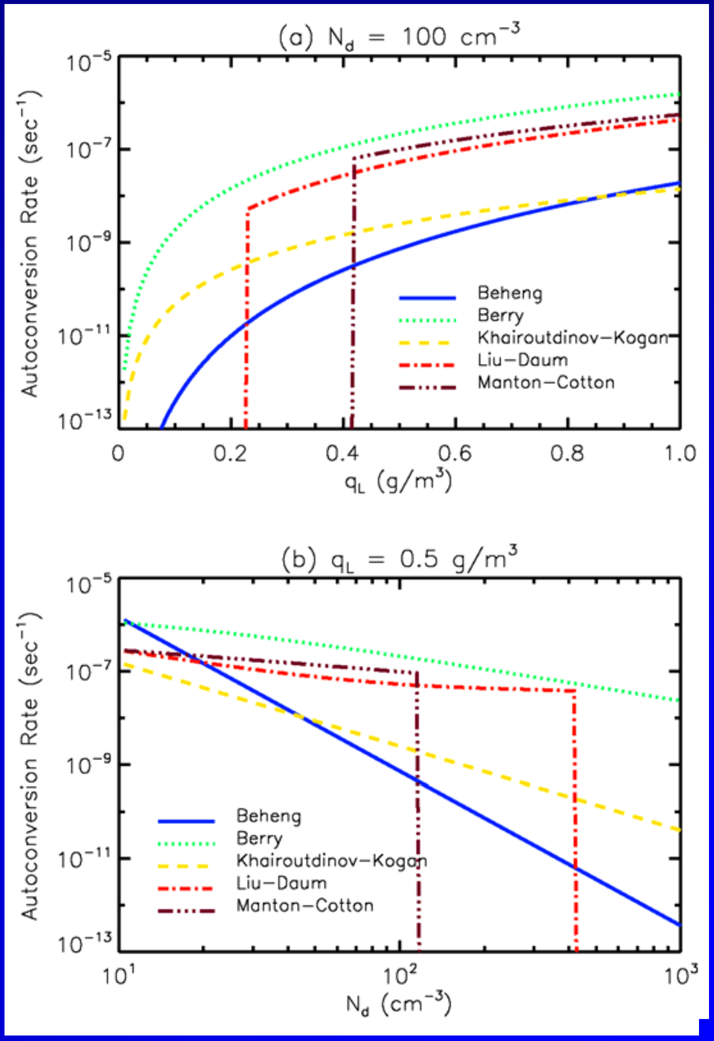
Liu-Daum (2004)

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

Manton-Cotton (1977, CAM3 Default)

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

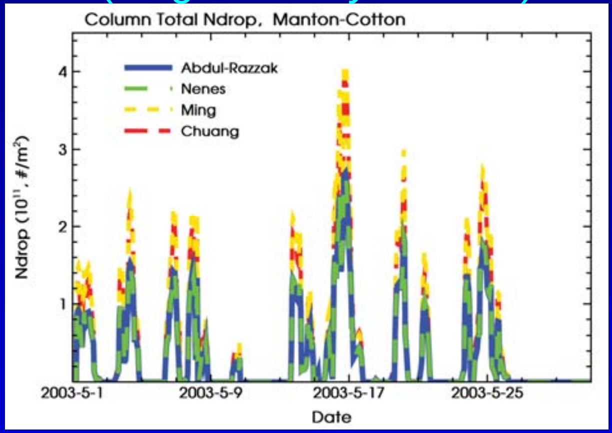
Autoconversion Rate



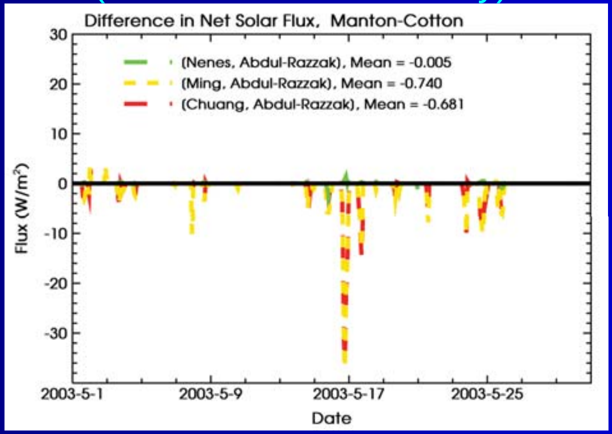
Sensitivity to Nucleation Parameterization
(with autoconversion scheme from Manton-Cotton)

- CAM3.5 with prescribed aerosol climatology was initialized and performed 3 day forecasts for the period of May 2003 Aerosol IOP conducted over the SGP site.
- Results shown here are the composite of 6-30 hour forecasts.

Column Ndrop
(diagnostically derived)

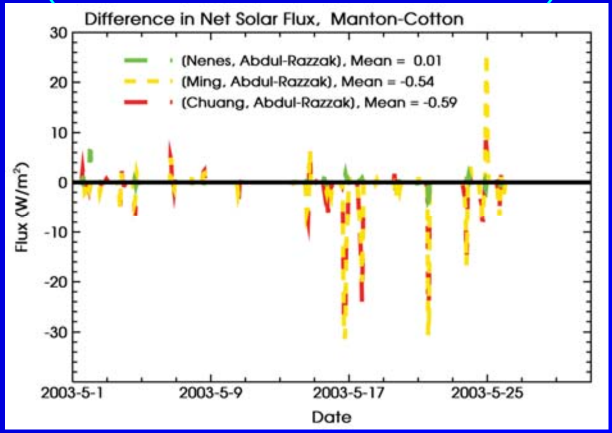


Δ TOA Net SW
(cloud albedo effect only)



constant LWP,
higher Nd
→ higher albedo
→ lower net SW

Δ TOA Net SW
(cloud albedo + lifetime effects)

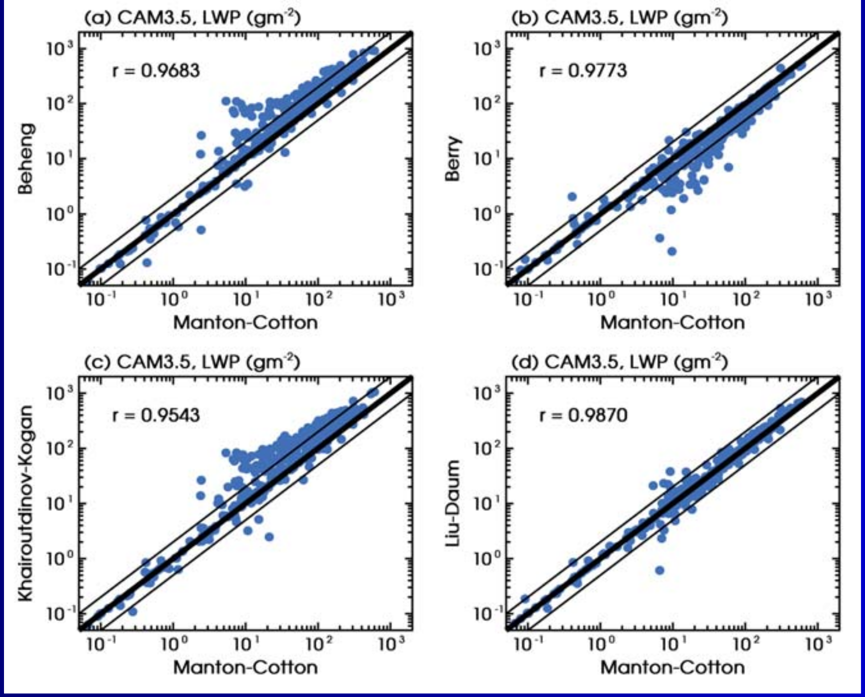


similar pattern, for some conditions ΔNd modify cloud fraction & lifetime, higher net SW

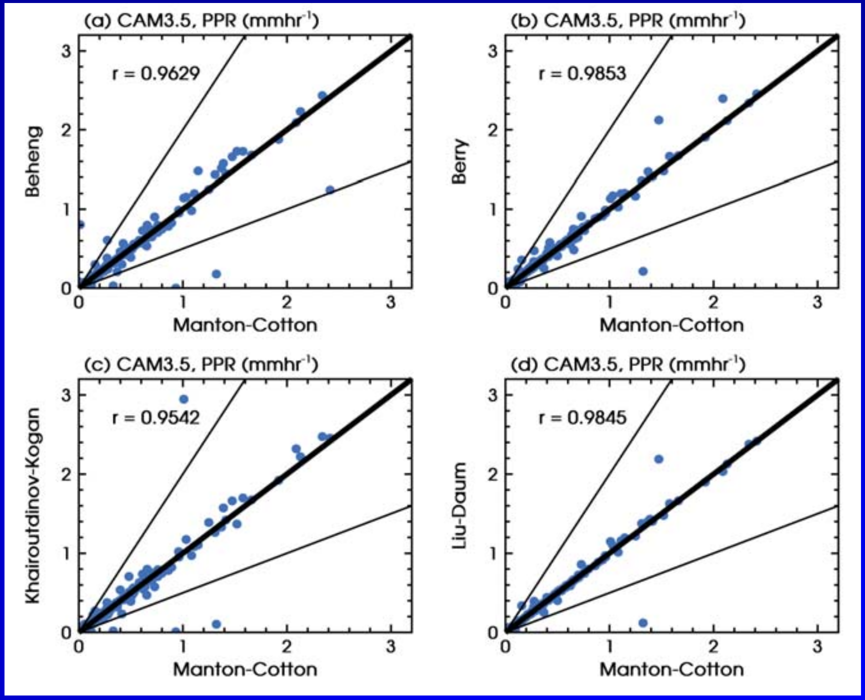
Sensitivity to Autoconversion Scheme (1)
(with nucleation parameterization from Abdul-Razzak)

- Scatter plots between modified and default (Manton-Cotton) schemes

Liquid Water Path



Precipitation Rate

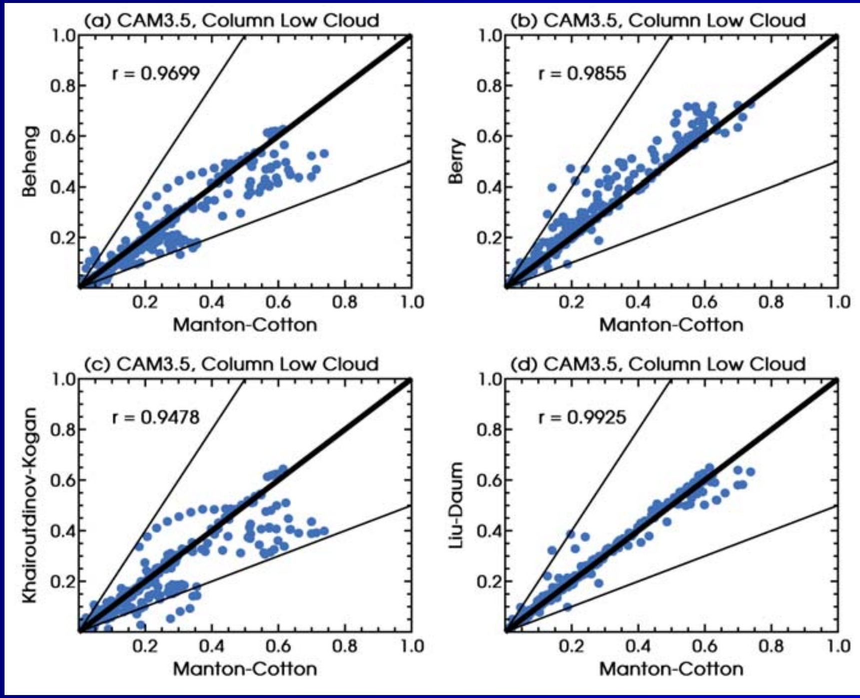


higher autoconversion rate → lower LWP

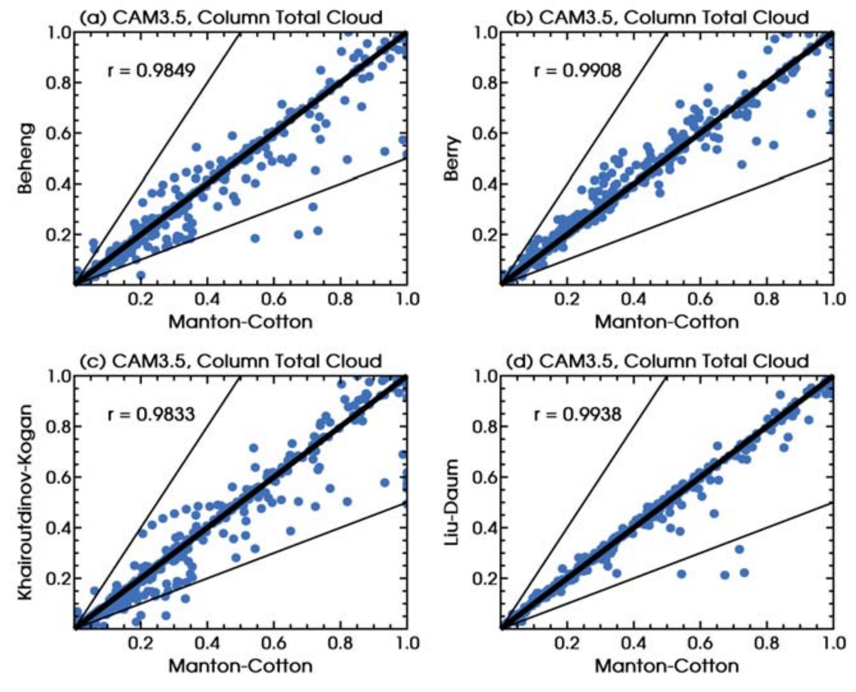
Sensitivity to Autoconversion Scheme (2)
(with nucleation parameterization from Abdul-Razzak)

- Assume maximum-random overlap, $P_{Low\ cloud}$ > 700 mb

Low Cloud Cover



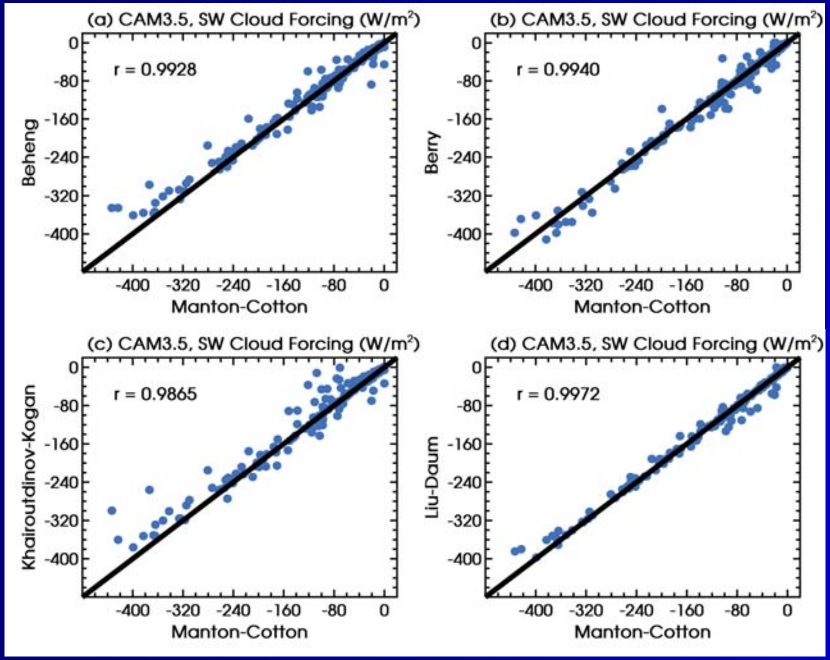
Total Cloud Cover



higher autoconversion rate → lower LWP
(higher rain mixing ratio)
Evaporation of rain → higher RH
→ higher cloud cover

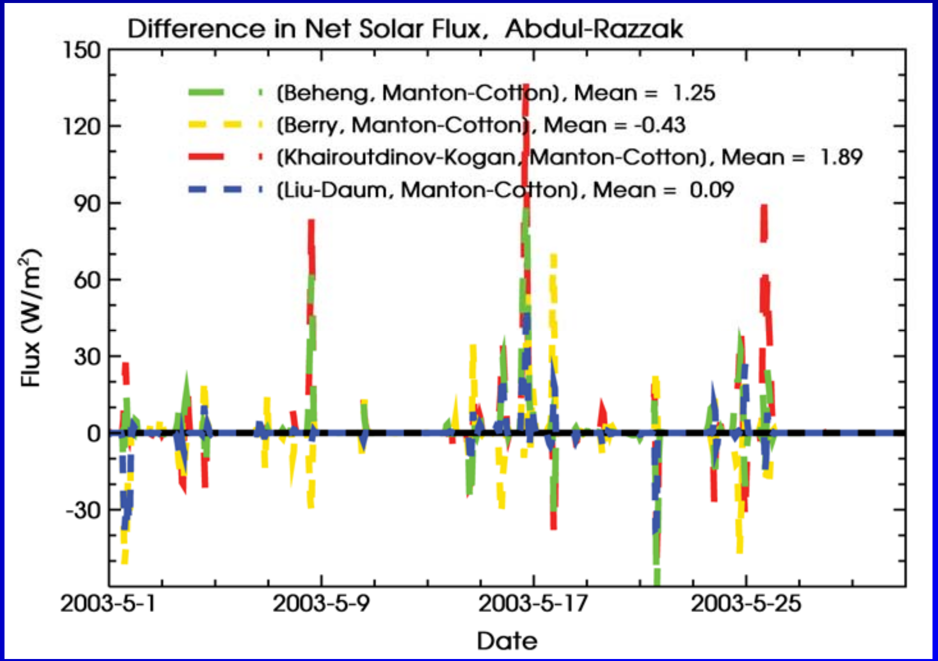
Sensitivity to Autoconversion Scheme (3)
(with nucleation parameterization from Abdul-Razzak)

SW Cloud Forcing



higher autoconversion rate
→ lower LWP, higher cloud fraction
→ higher (negative) SW cloud forcing
→ Lower TOA Net SW

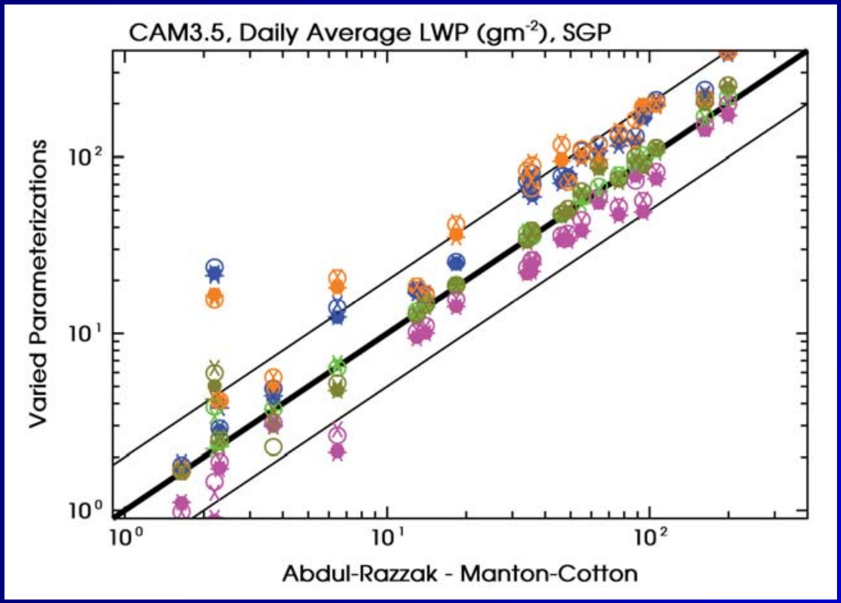
Δ TOA SW between schemes



- Hourly variations between different schemes are large (up to 140 W/m^2)
- Monthly average is only up to 2 W/m^2 due to the competition between LWP and cloud faction.

Combined Sensitivity

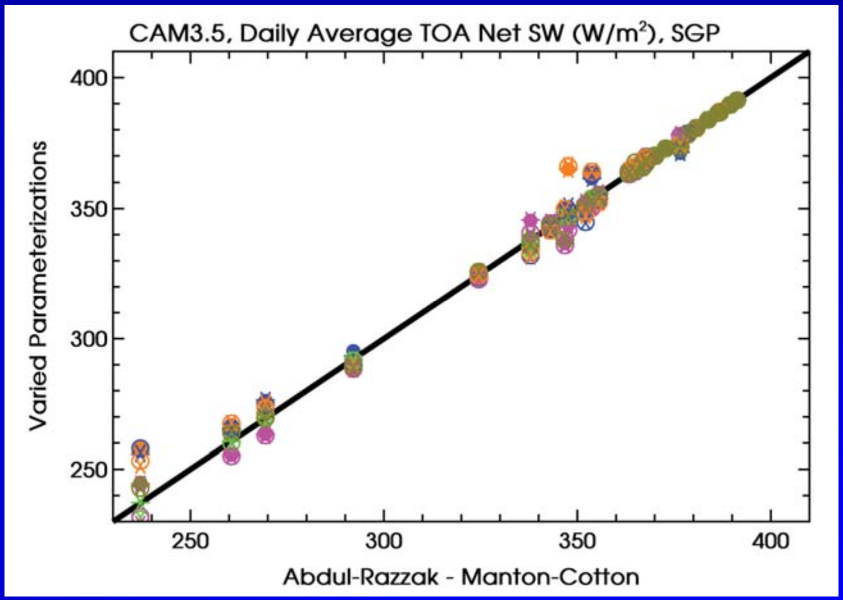
Daily average LWP



Nucleation
- ● Abdul-Razzak
- ✳ Nenes
- ○ Ming
- X Chuang

Autoconversion
- Manton-Cotton
- Beheng
- Berry
- Khairoutdinov-Kogan
- Liu-Daum

TOA SW between parameterizations
(cloud albedo + lifetime effects)



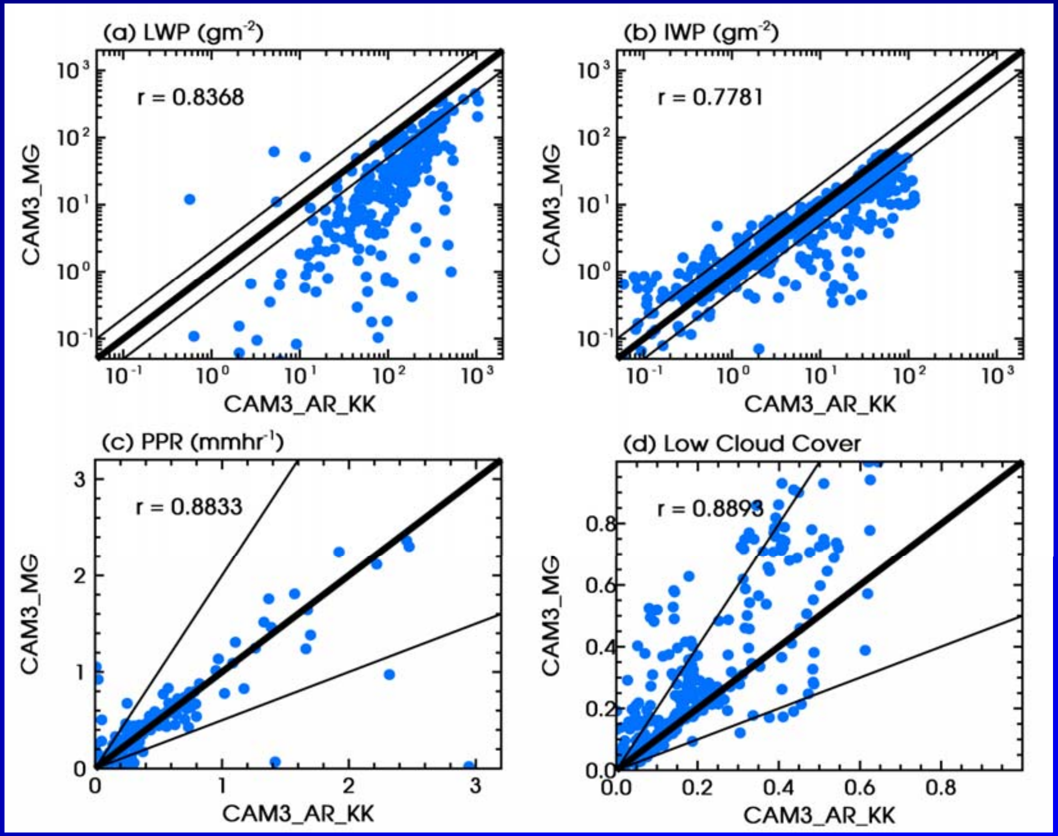
Comparison between the modified CAM3.5 default cloud microphysics and Morrison-Gettelman package

Same

- Aerosol mass concentrations
- Nucleation parameterization:
  Abdul-Razzak
- Autoconversion scheme:
  Khairoutdinov-Kogan

Different

- Aerosol size distribution
- Prognostic treatment for number concentrations of cloud drops and ice particles in MG

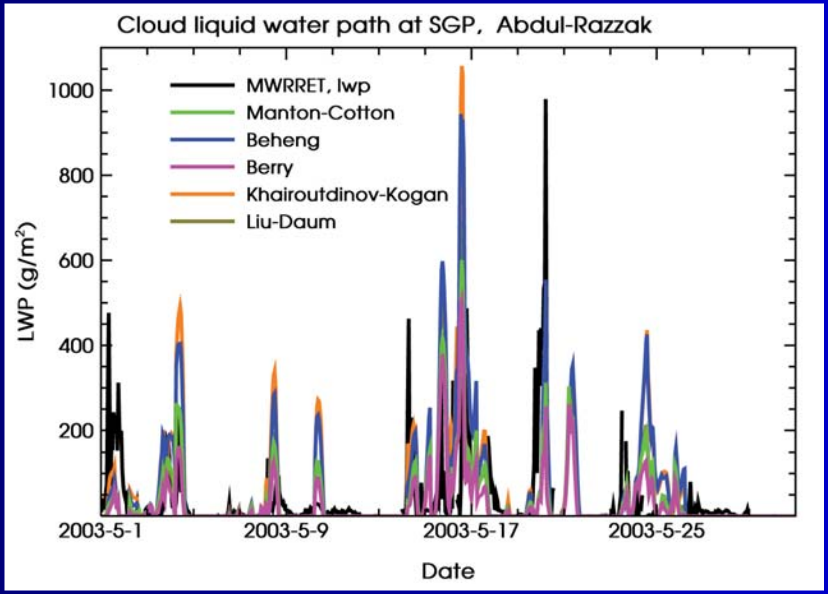


- LWP and IWP are lower for MG
- Low cloud cover is higher for MG

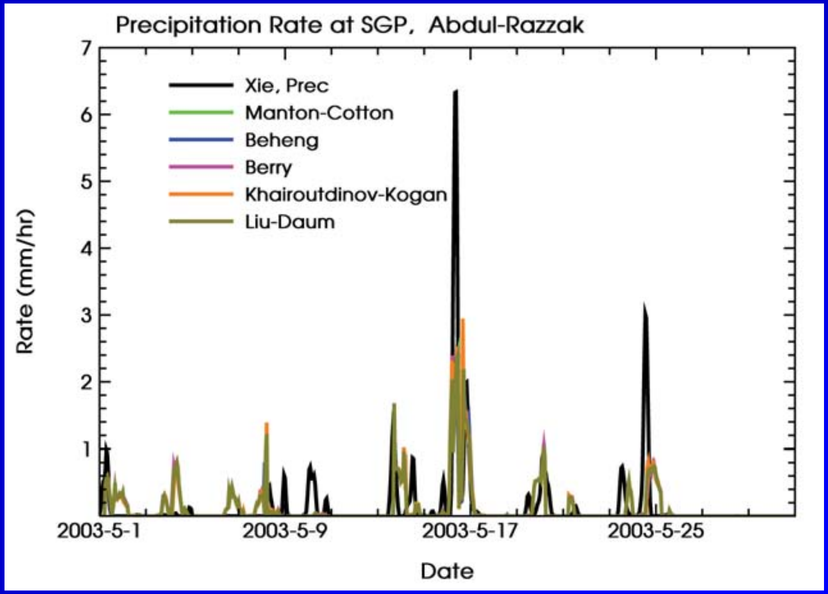
Compare to ARM Data (1)

- LWP: MWRRET (Microwave Radiometer Retrievals) best estimate
  PI Data Product: D. Turner (http://iop.archive.arm.gov/arm-iop/0pi-data/turner/)
- Precipitation Rate: Arkansan Basin Red River Forecast Center rain gauge data adjusted by radar measurements
  PI Data Product: S. Xie (http://iop.archive.arm.gov/arm-iop/0pi-data/xie/)

LWP

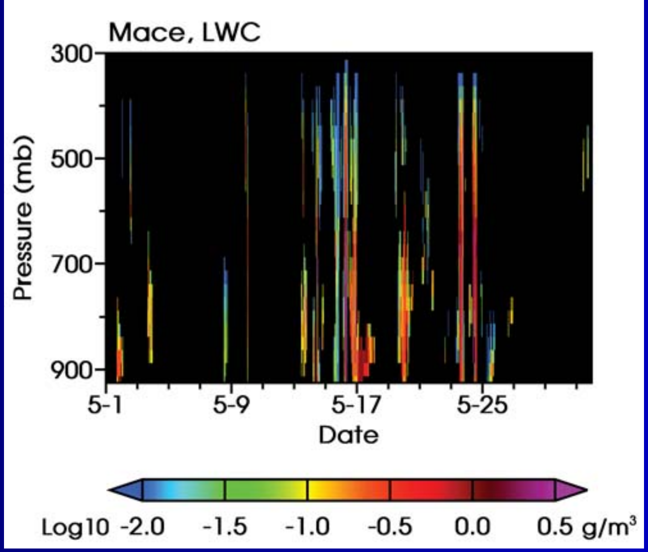


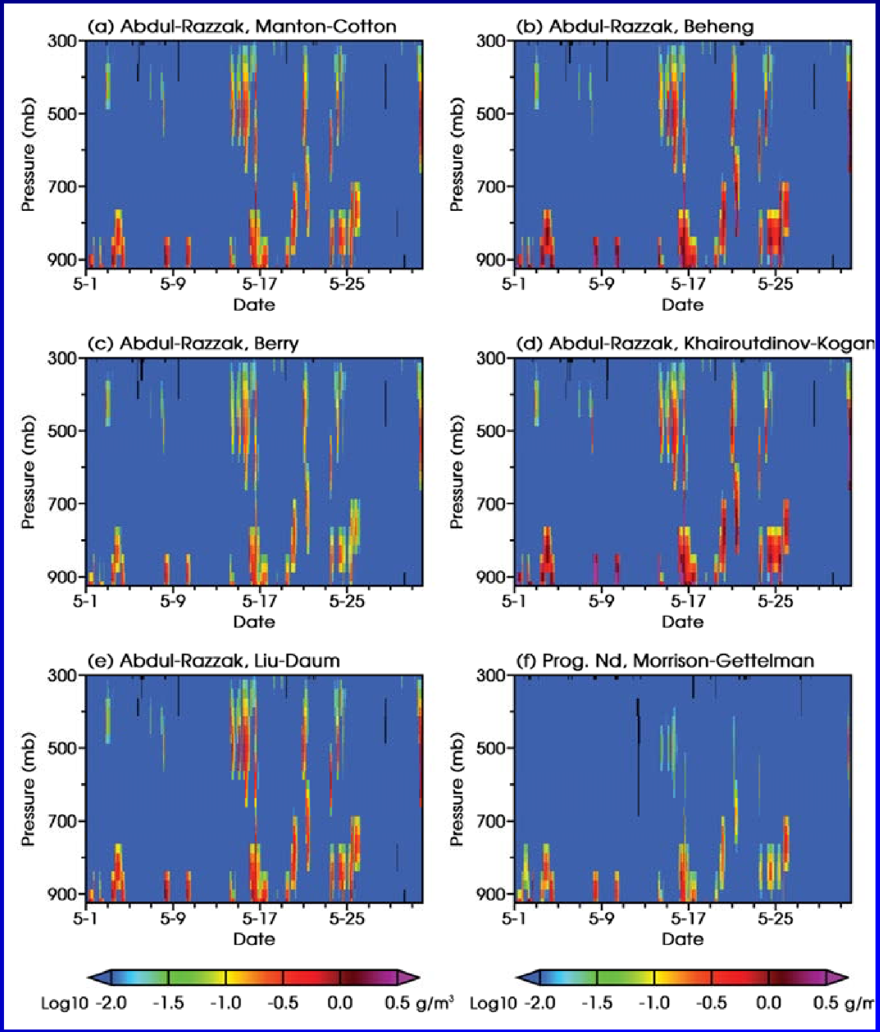
Precipitation Rate



Compare to ARM Data (2)

- LWC: Mace's Cloud Microphysical Properties regridded for CPM WG





Summary

- Nucleation parameterizations by Nenes and Abdul-Razzak yield comparable TOA SW at SGP.
- Similar forecasts with autoconversion schemes by Manton-Cotton and Liu-Daum.
- Cloud properties and radiative fluxes are more sensitive to the treatment of autoconversion than that for cloud nucleation.
- During May 2003 IOP, the average of CAM3 calculated TOA SW at SGP differs by up to 2 W/m^2 with different treatments of aerosol/cloud interactions.
- Next step:

  Sensitivity of IE (= $d\ln R_e / d\ln \tau_a$) to cloud parameterizations will be explored in global scale.
- Future work:

  Apply CAM3 with interactive aerosols .

  Compare IE with those derived from ARM data at SGP.

IE for LWP > 0.5 kg/m^2