Cloud - Aerosol Interactions in the Community Climate System Model

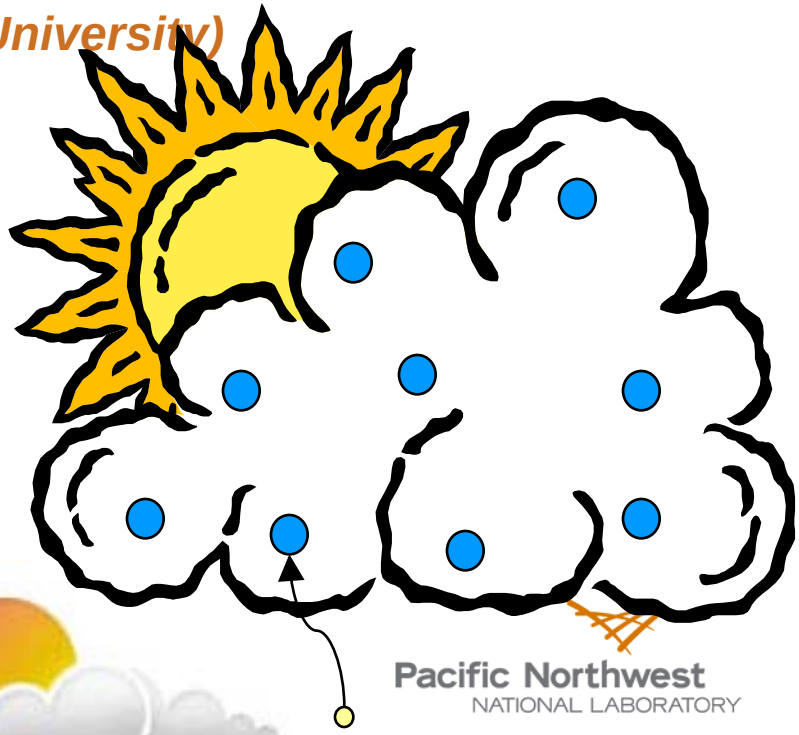
S. Ghan, X. Liu, R. Easter, R. Zaveri, P. Rasch (PNNL)

H. Morrison, A. Gettelman, Sungsu Park, J.-F. Lamarque, F. Vitt (NCAR)

Chris Bretherton (U. Washington)

P. Hess, N. Mahowald (Cornell University)

A. Ekman (Stockholm University)



Versions of Community Atmosphere Model

- CAM3
  - Used for IPCC AR4
  - Interactive sulfate
  - Prescribed carbonaceous, dust, sea salt
  - Aerosol effects on solar radiation
  - No aerosol effect on clouds
- CAM4
  - Being used for IPCC AR5
  - Interactive externally-mixed bulk aerosol
  - Aerosol effects on solar radiation
  - No aerosol effect on clouds
  - Improved representation of dilution in deep convective clouds
- CAMap

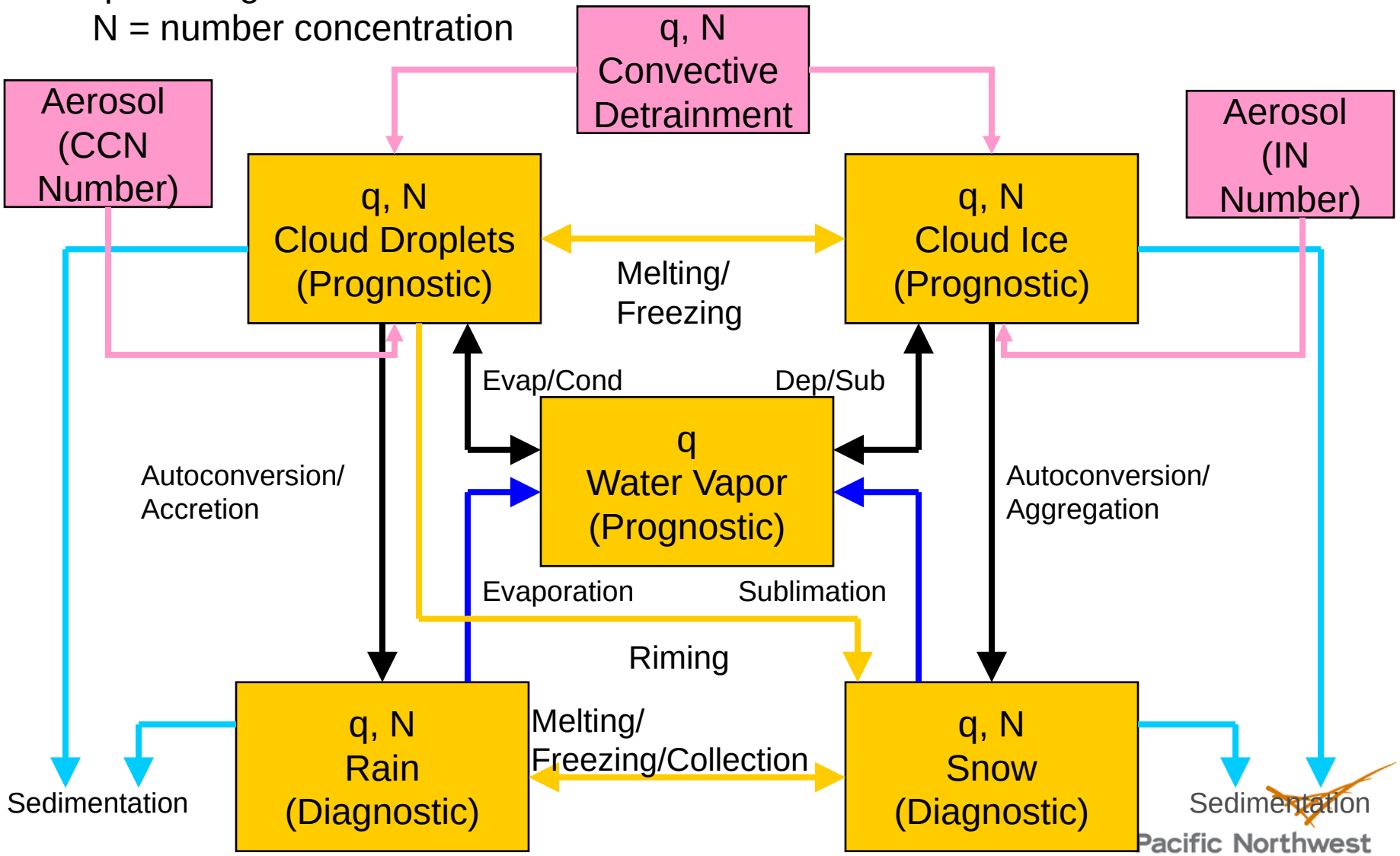
CAMap

- Morrison & Gettelman double-moment stratiform cloud microphysics
- Modal Aerosol Model
- Aerosol effects on stratiform droplet and crystal number
- Bretherton and Park (2009) moist turbulence scheme
- Park and Bretherton (2009) shallow cumulus scheme
- Cloud fraction consistent with PDF of total water
- RRTMG radiation package
- Advanced optics for cloud and aerosol particles

Stratiform Cloud Processes

Morrison and Gettelman, J. Climate, 2008

q = mixing ratio
N = number concentration



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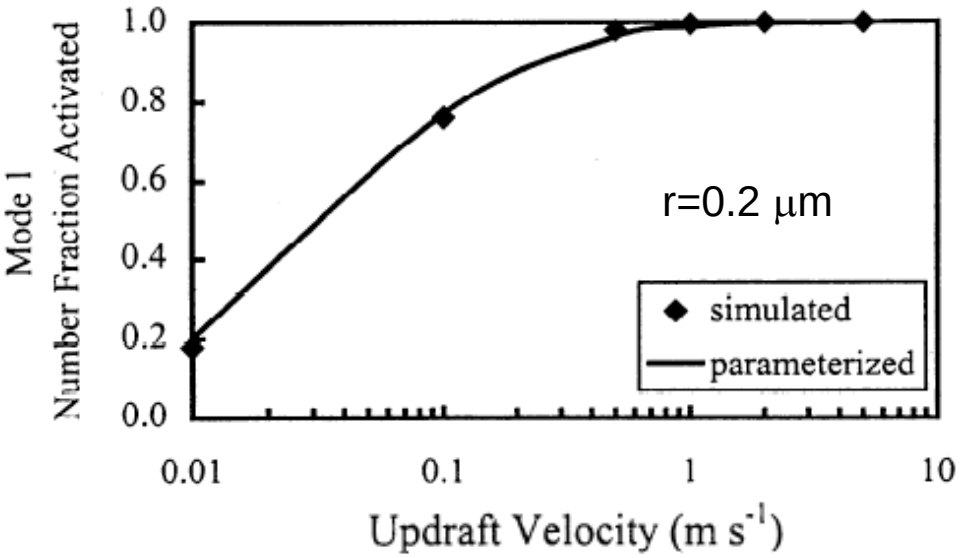
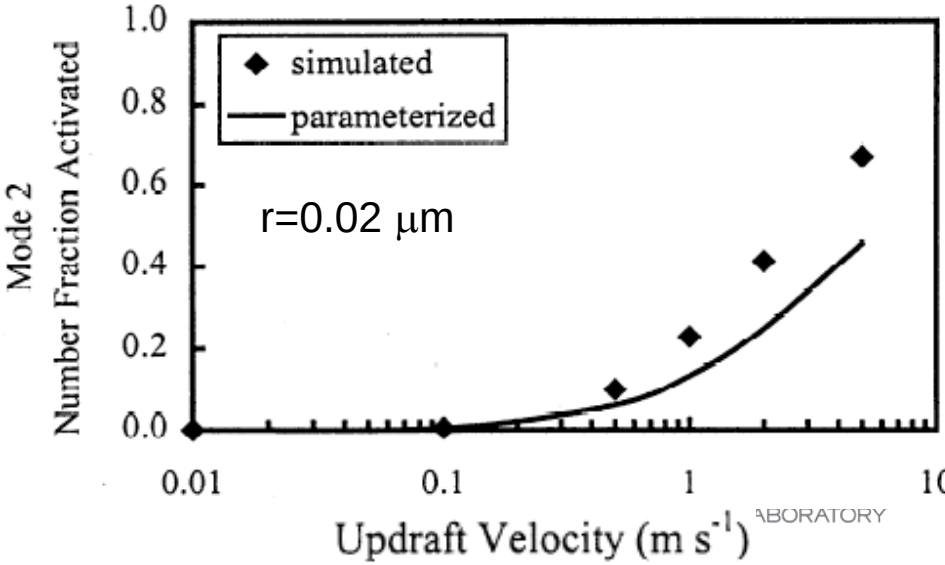
Droplet nucleation

- Number nucleated is parameterized in terms of updraft velocity and the properties of all of the aerosol modes (Abdul-Razzak and Ghan, 2000)
- Nucleation is assumed to occur as
  - updrafts carry air into the base of the cloud (Ghan et al., 1997)
  - cloud fraction increases (Ovtchinnikov and Ghan, 2005)
  - new clouds form while old clouds dissipate
- PDF of updraft velocity approximated by δ function σ_w





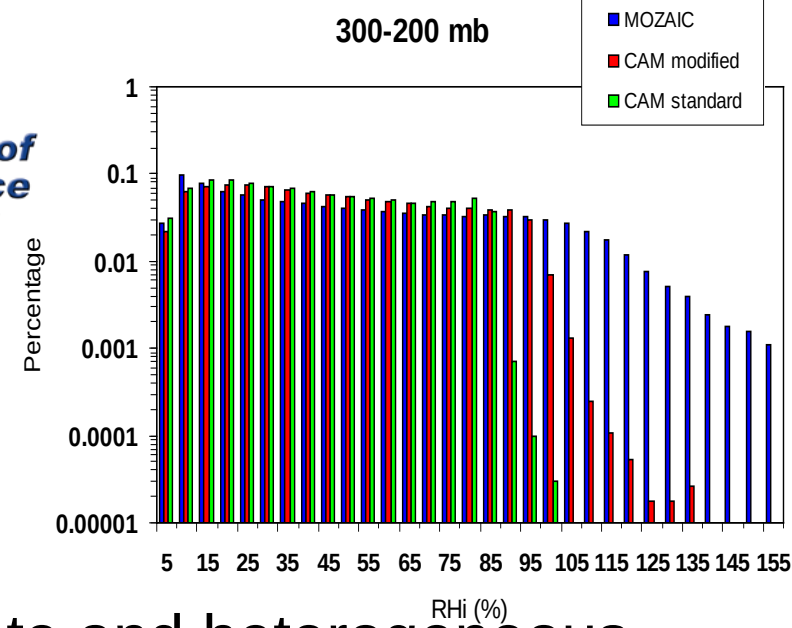
Autoconversion of droplets to rain

- Khairoutdinov and Kogan (2000) used for dependence on local cloud water mass and number mixing ratio

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

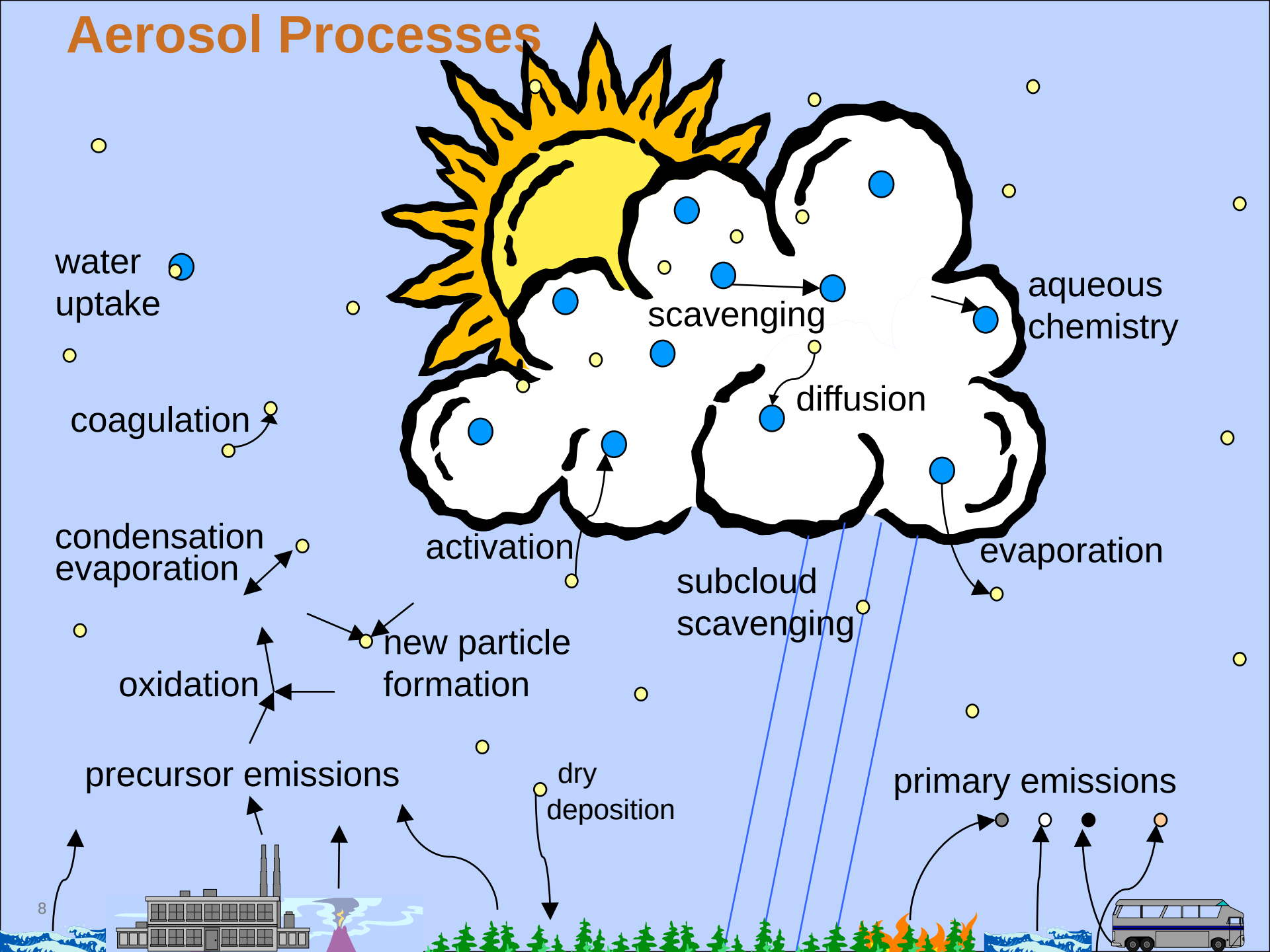
- Influence of subgrid variability of cloud water within cloud treated by integrating over gamma PDF of cloud water

Crystal nucleation
Liu et al., J. Climate, 2007



- Ice supersaturation permitted
- Homogeneous nucleation of sulfate and heterogeneous immersion nucleation on dust compete in cirrus clouds with T<-35C (Liu & Penner, 2005)
- Contact freezing of cloud droplets in mixed-phase clouds (-35 to 0 C) based on Young (1974), and assume contact IN to be mineral dust (Brownian coagulation)
- Deposition/condensation ice nucleation in mixed-phase clouds (-35 to 0 C) based on Meyers et al. (1992)
- Secondary ice production between -3 and -8 C based on Cotton et al. (1986) for Hallet-Mossop multiplication

Aerosol Processes



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

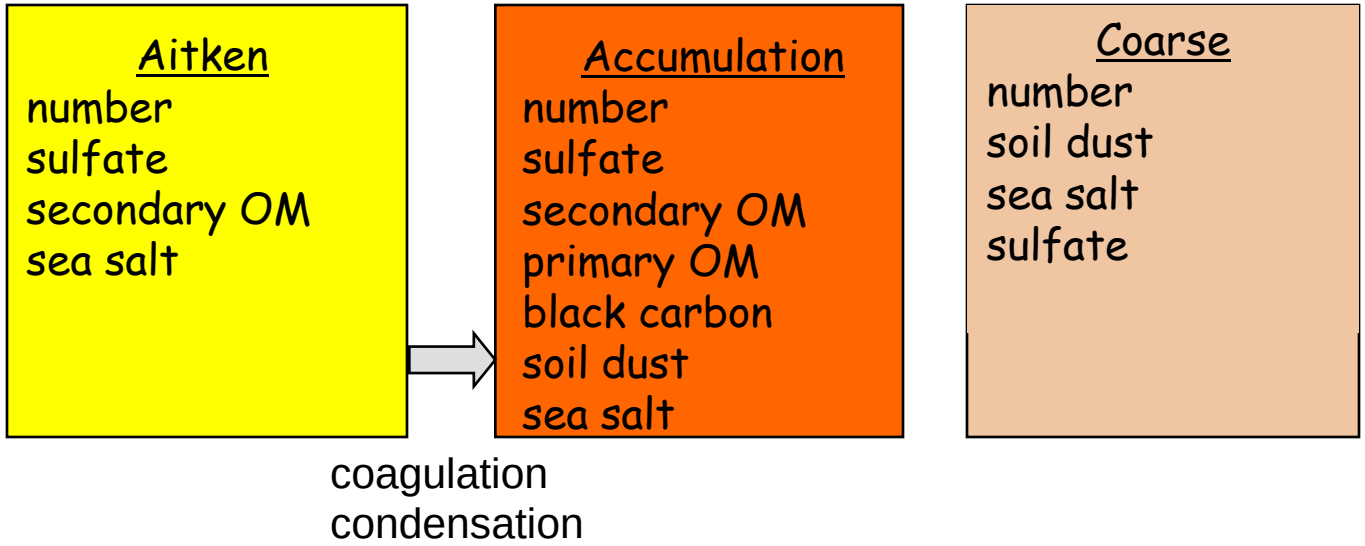
All modes log-normal with prescribed width.

Total transported aerosol tracers: 31

Cloud-borne aerosol predicted but not transported.

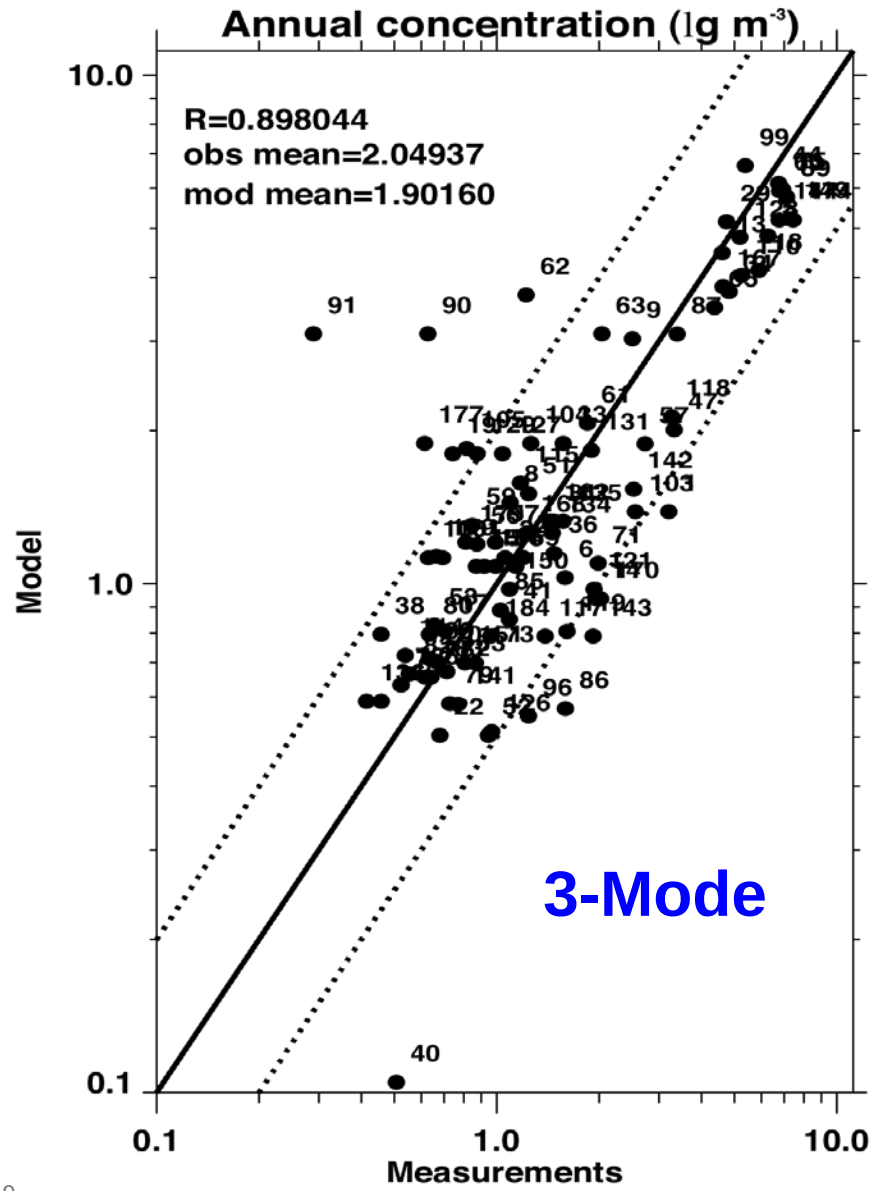
3-Mode Version of MAM

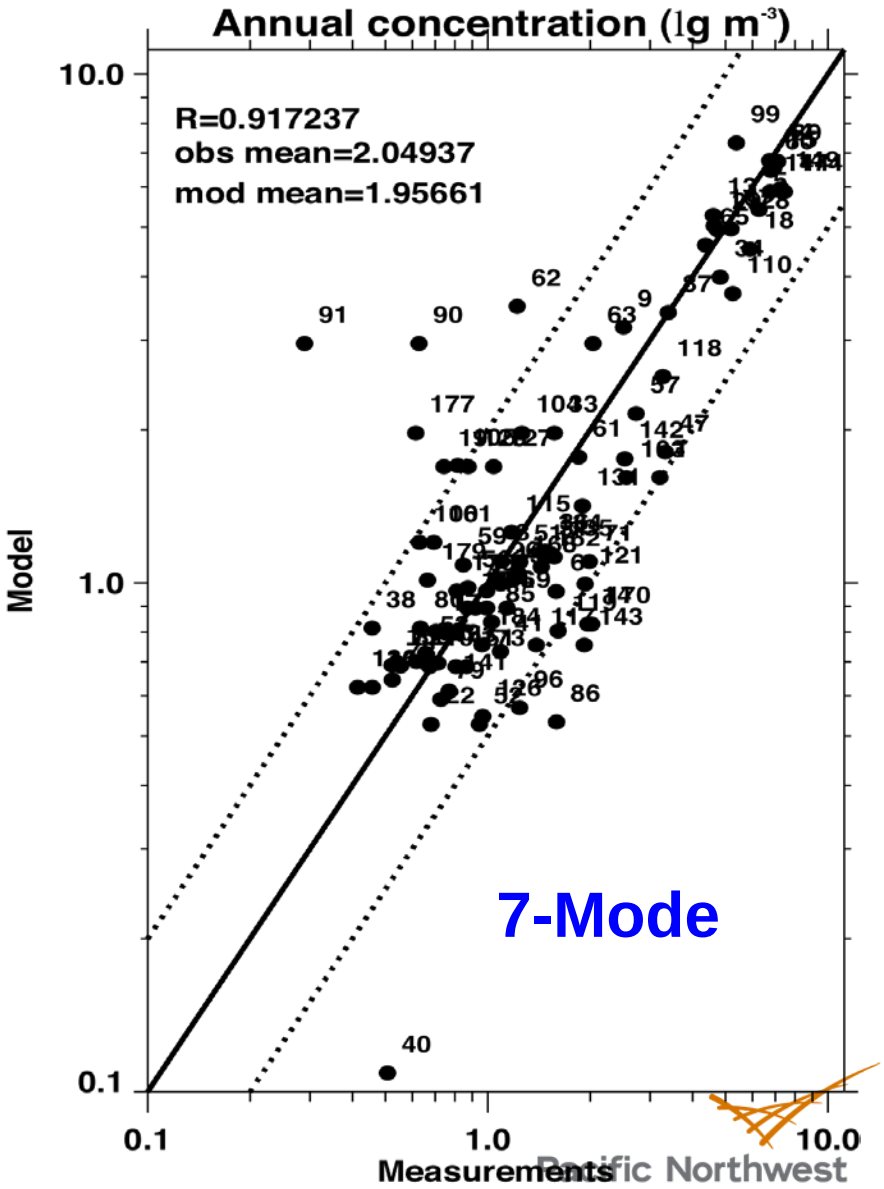
Assume primary carbon is internally mixed with secondary aerosol.
Sources of dust and seasalt are geographically separate
Assume ammonium neutralizes sulfate.



Total transported aerosol tracers: 15

SO_4 compared with IMPROVE data





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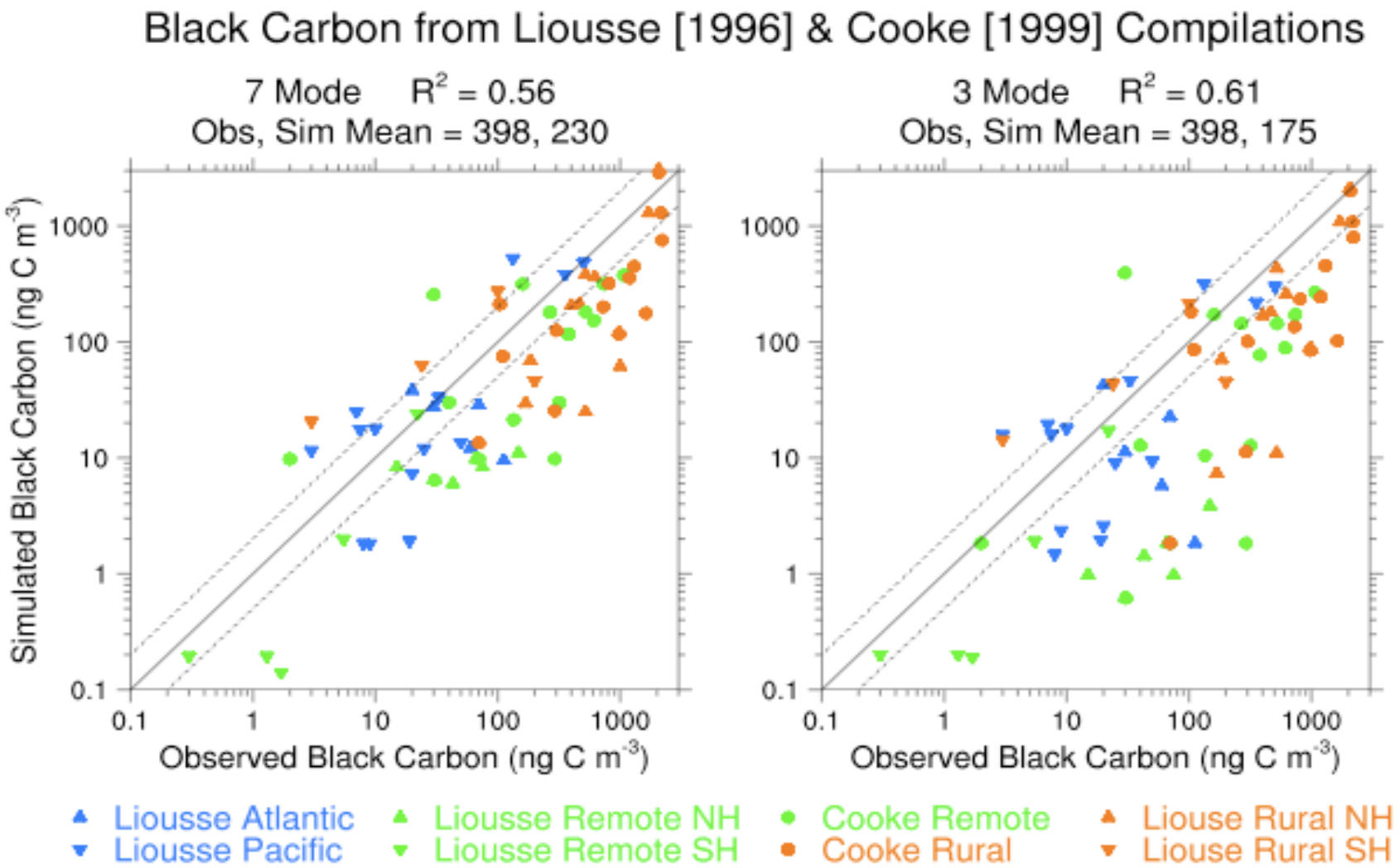
BC compared with global data



7-Mode **3-Mode**

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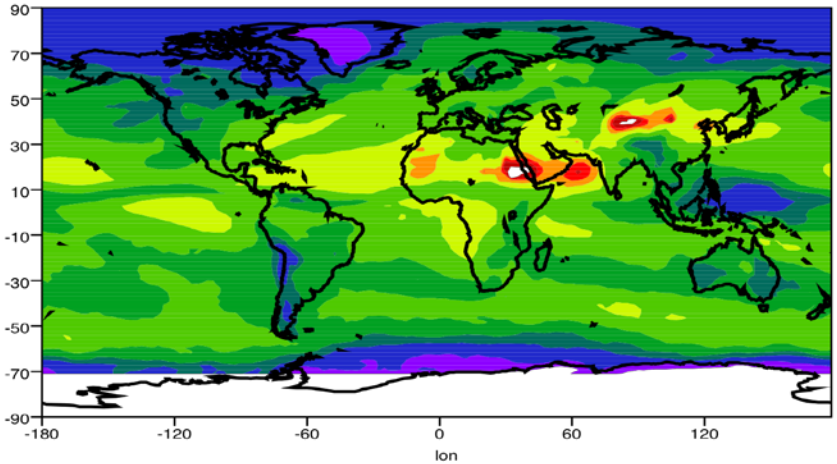
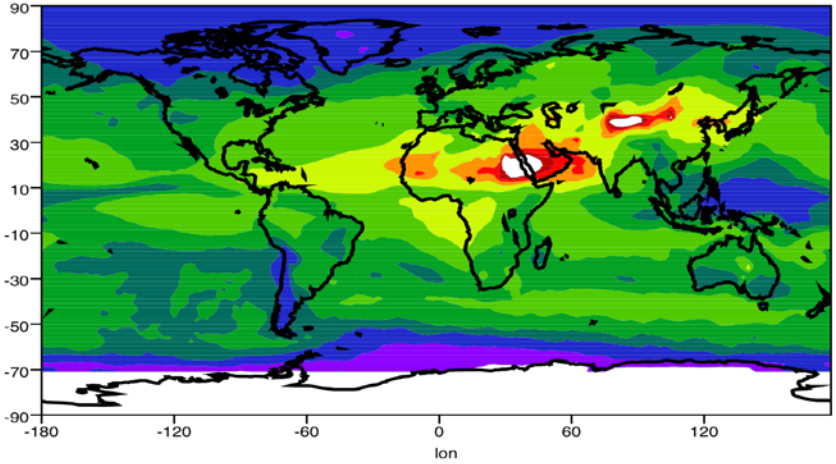
Aerosol Optical Depth - July

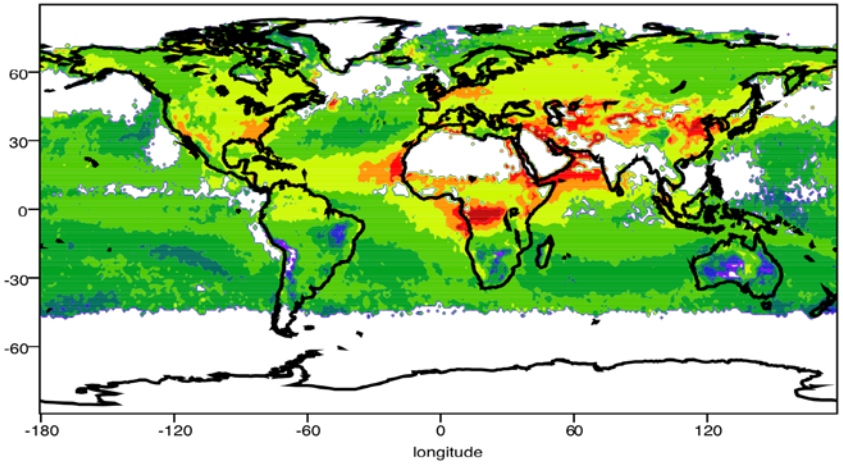
MAM3 AOD=0.13



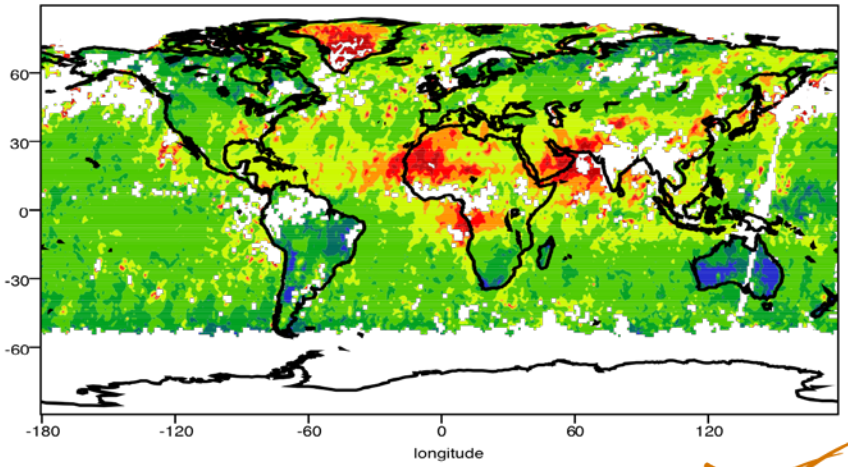
MAM7 AOD=0.12

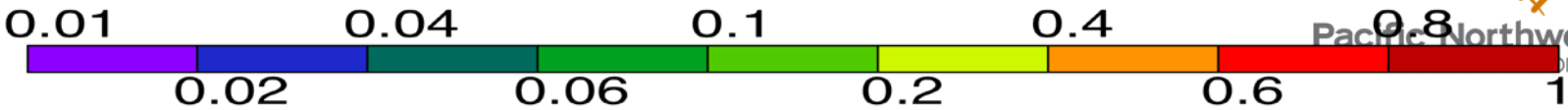


MODIS



MISR





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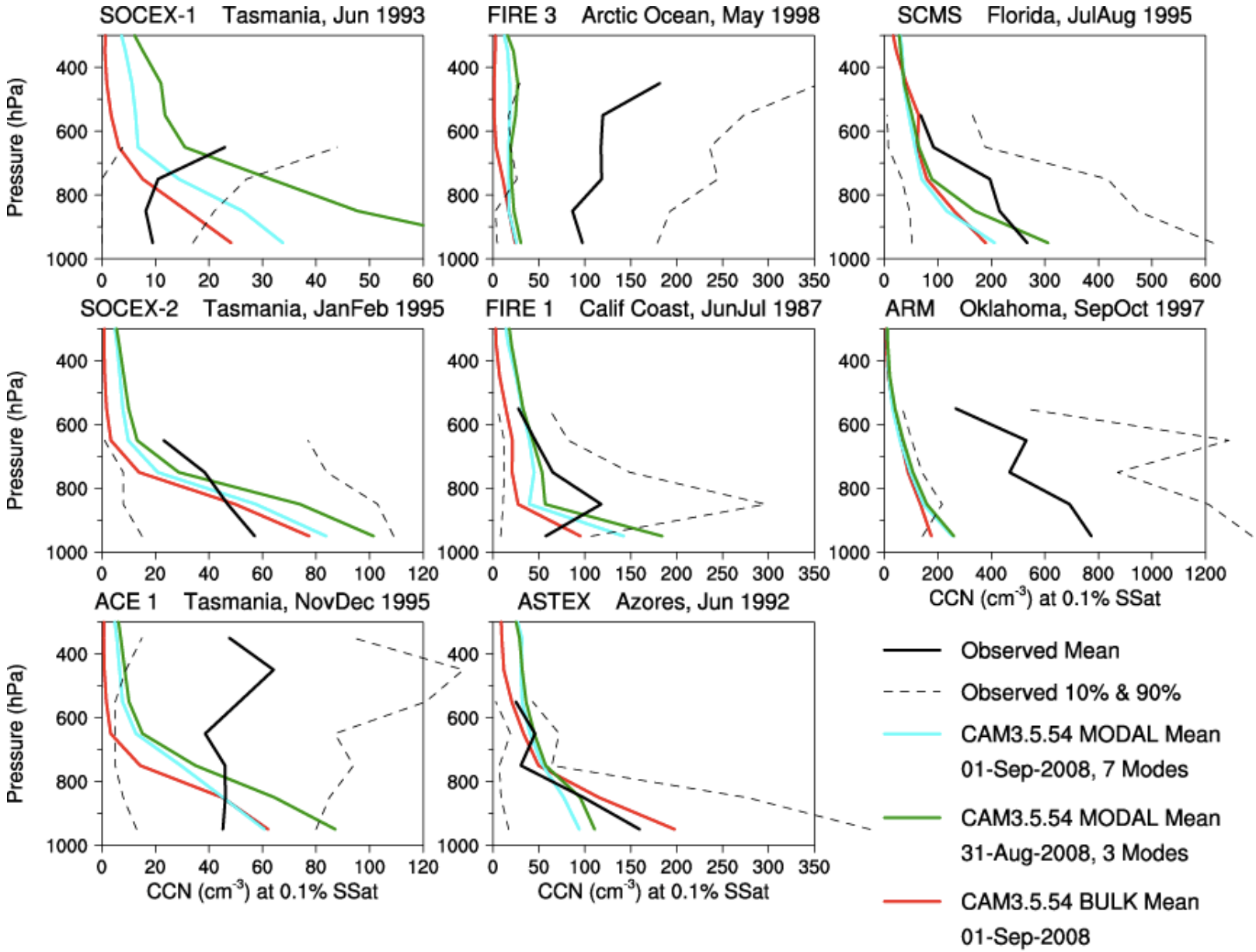
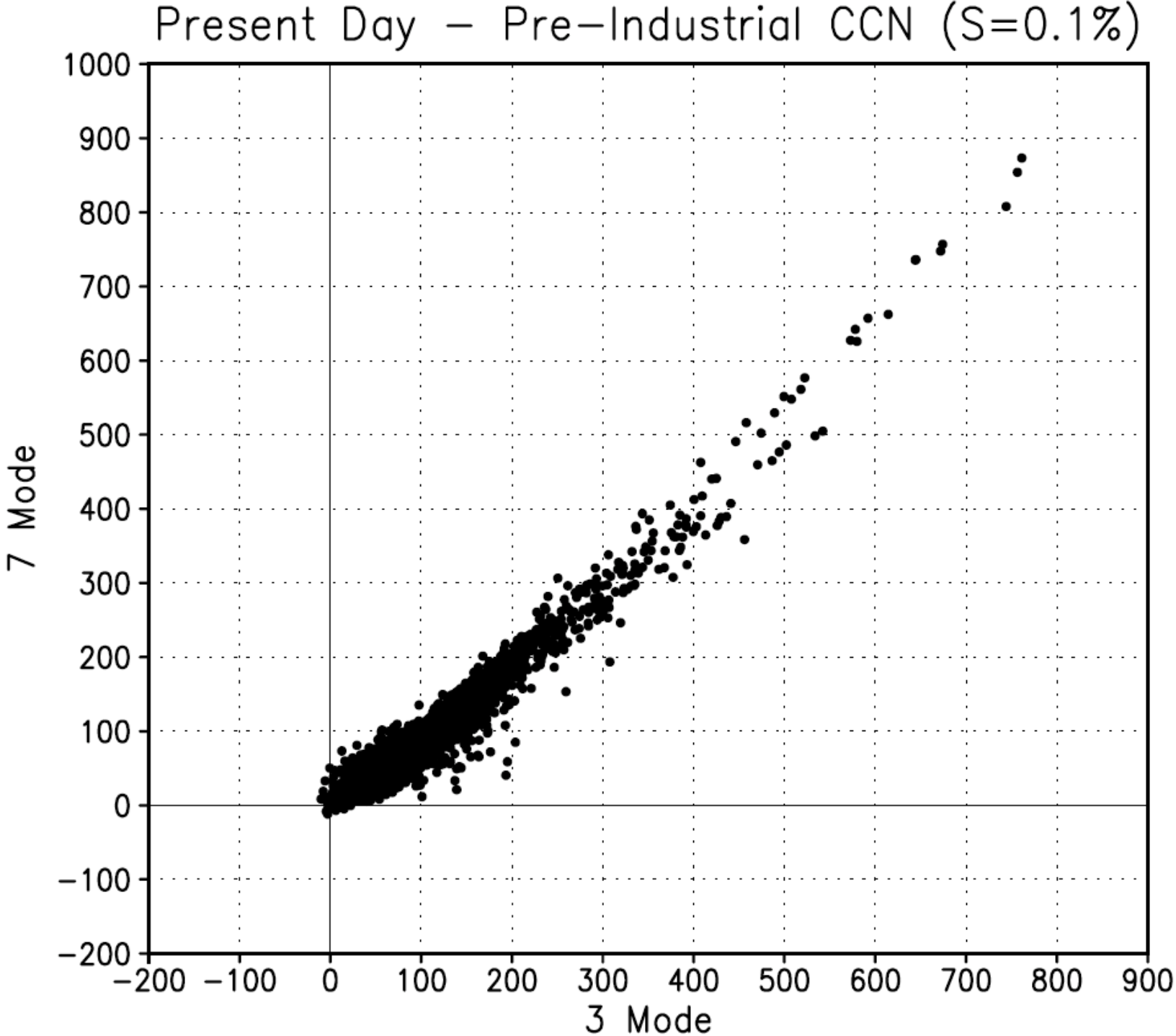
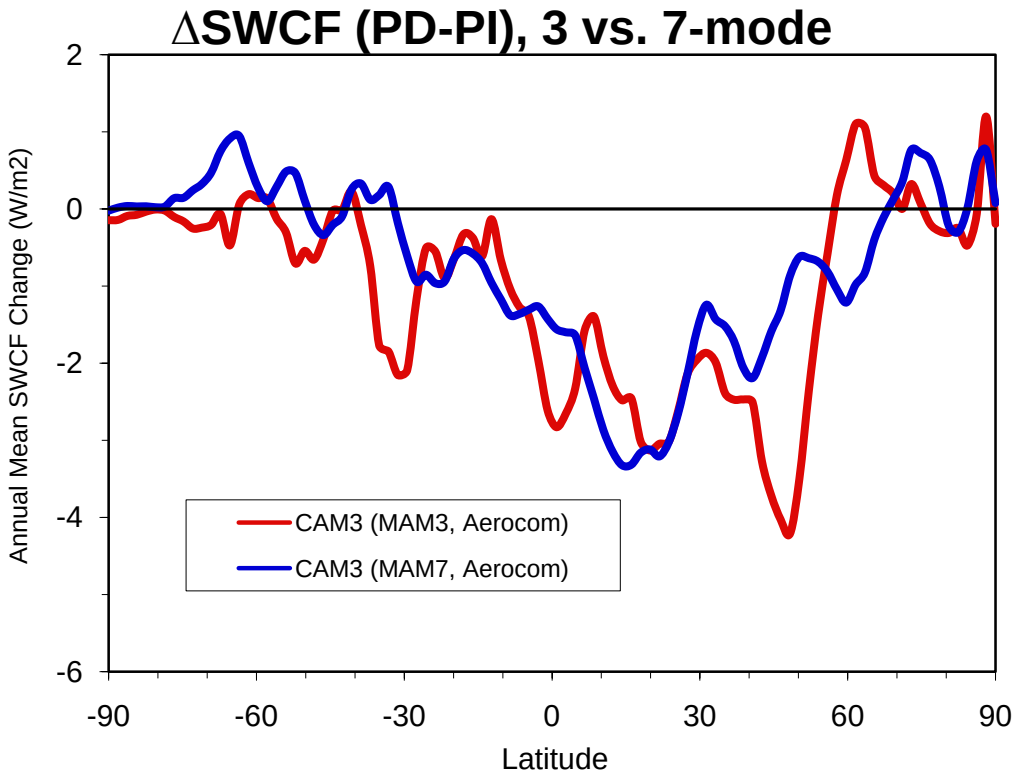
CCN Concentration (S=0.1%)




Present Day – Pre-Industrial CCN (S=0.1%)
7 Mode
3 Mode
1000
900
800
700
600
500
400
300
200
100
0
−100
−200
−200
−100
0
100
200
300
400
500
600
700
800
900

Anthropogenic Indirect Effect



MAM3

ΔSWCF (Wm^{-2}) = -1.4
ΔTOA (Wm^{-2}) = -2.0

MAM7

ΔSWCF (Wm^{-2}) = -1.1
ΔTOA (Wm^{-2}) = -1.7

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Challenges and Future Work

- Aerosol effects on shallow cumulus, including dependence on entrainment
- Improvements in aerosol effects on ice crystal nucleation
  - Laboratory experiments
  - Application of ISDAC data
- Subgrid variability in ice formation
- Double moment microphysics for deep convection

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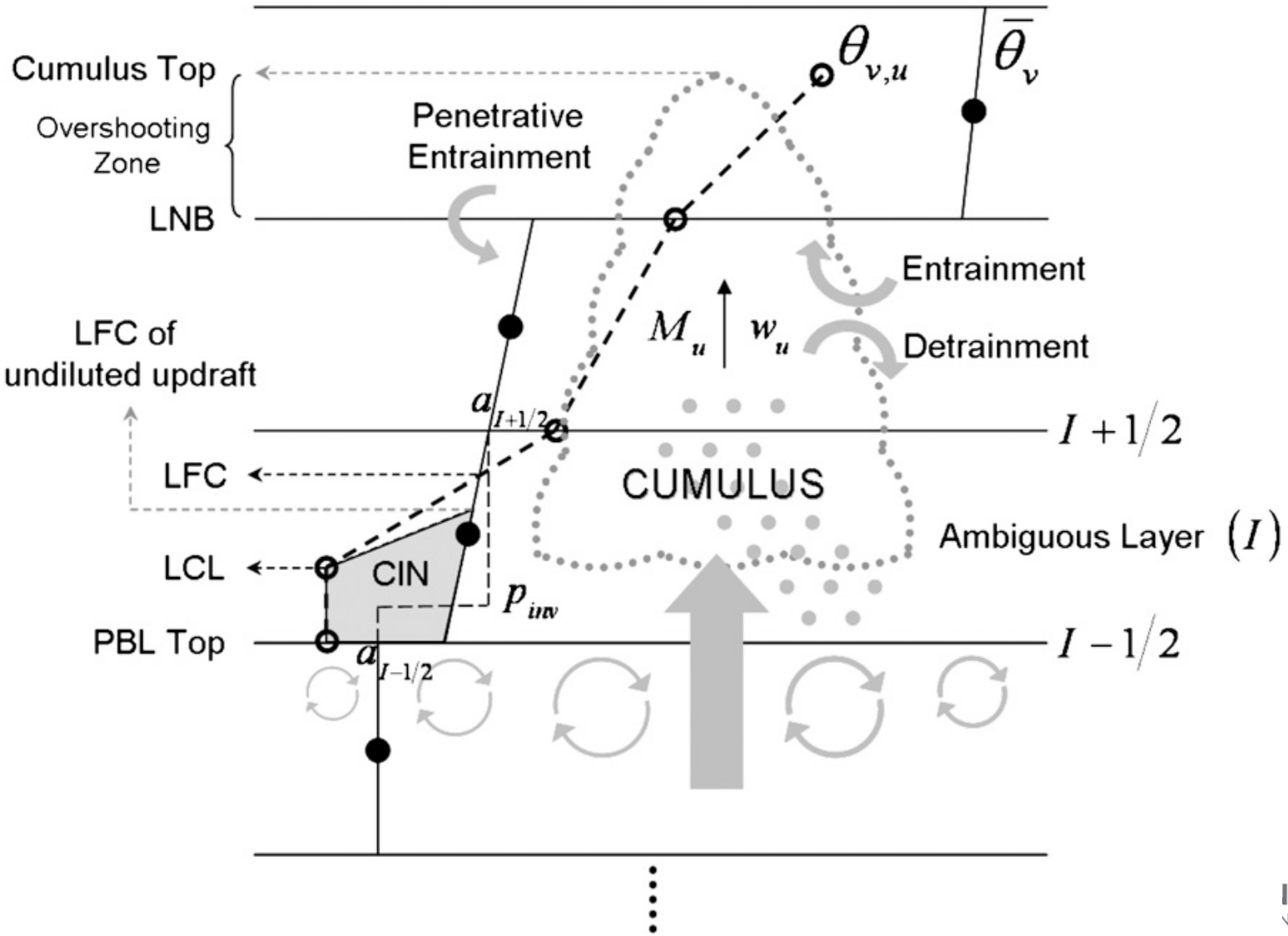
Shallow Cumulus Scheme
Park and Bretherton, J Climate 2009