Aerosol-Cloud Interactions in a Multiscale Aerosol Climate Model

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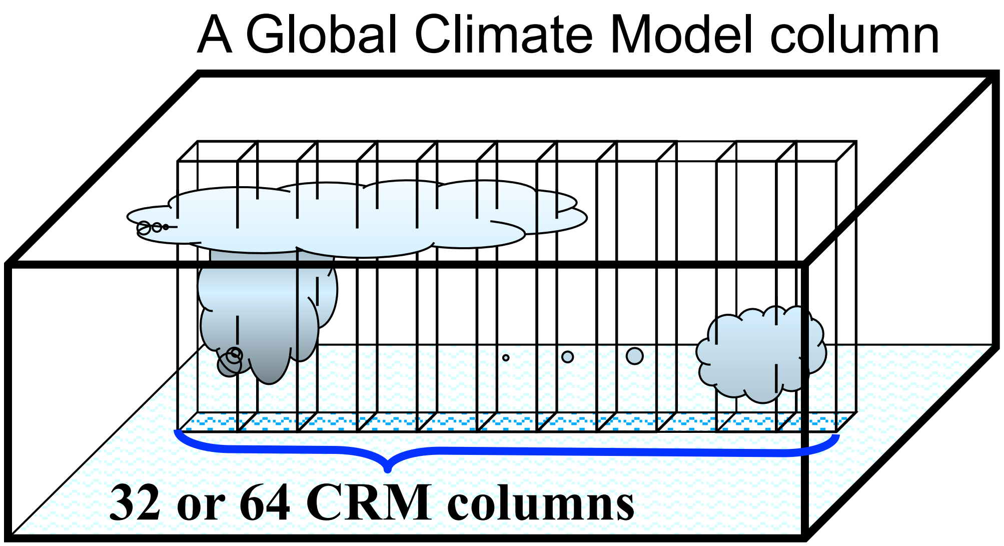
Motivation

- Anthropogenic aerosol effects on clouds are one of the largest uncertainties in projecting future climate change.
- Much of this uncertainty arises from the multiscale nature of the interactions between clouds, aerosols and large-scale dynamics.
- Convective clouds are the most problematic.

  - Aerosol effects on convective clouds are not represented or only crudely represented.

  - Convective processes (transport, wet scavenging, and aqueous chemistry) strongly affect aerosols, and parameterizations of convective processes are highly uncertain.

Multiscale Modeling framework Approach (MMF) (Superparameterization)



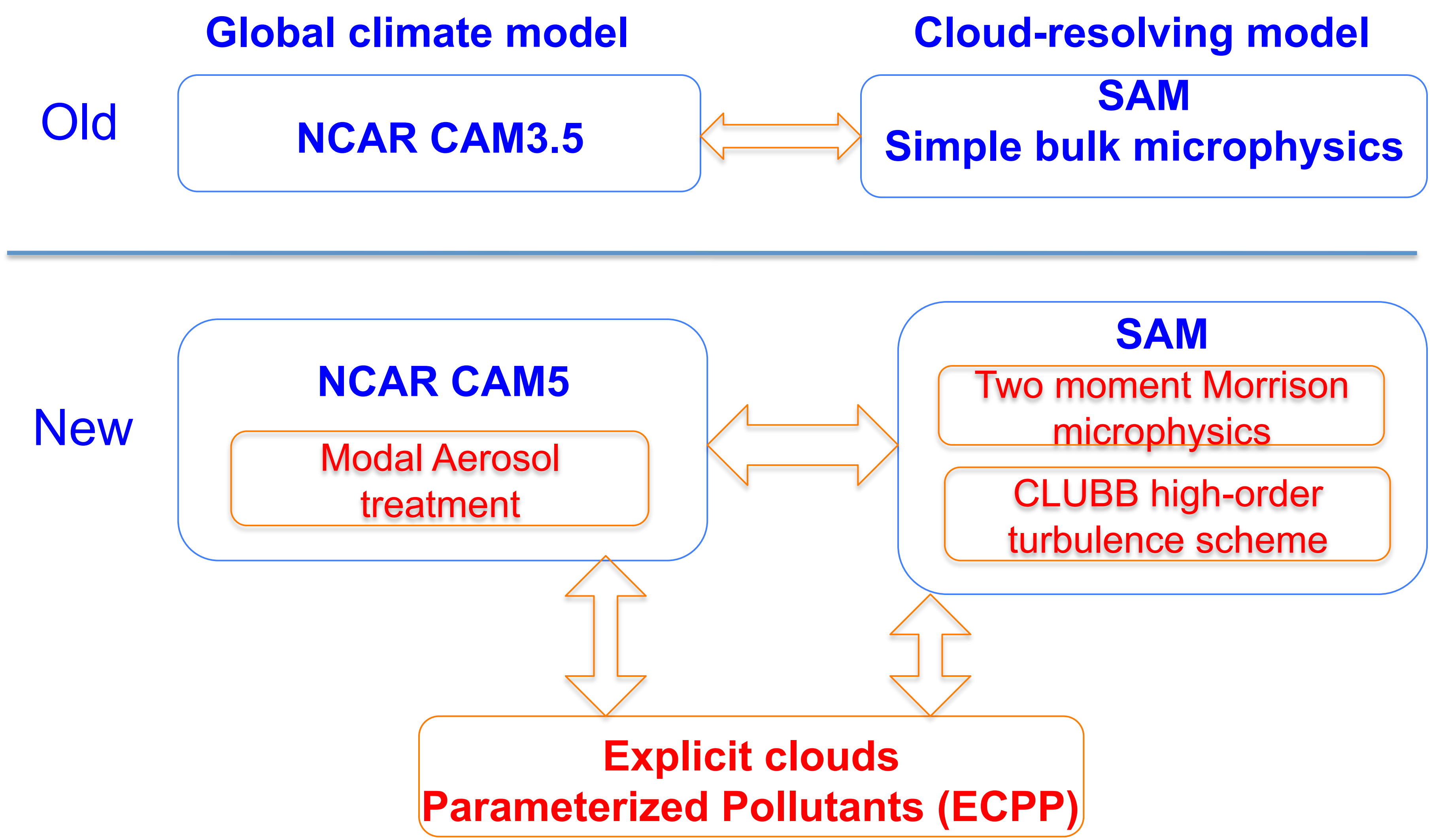
Grabowski, 2001; Khairoutdinov and Randall, 2001.

The MMF approach permits explicit simulations of deep convective clouds.

Limitations in the original MMF:

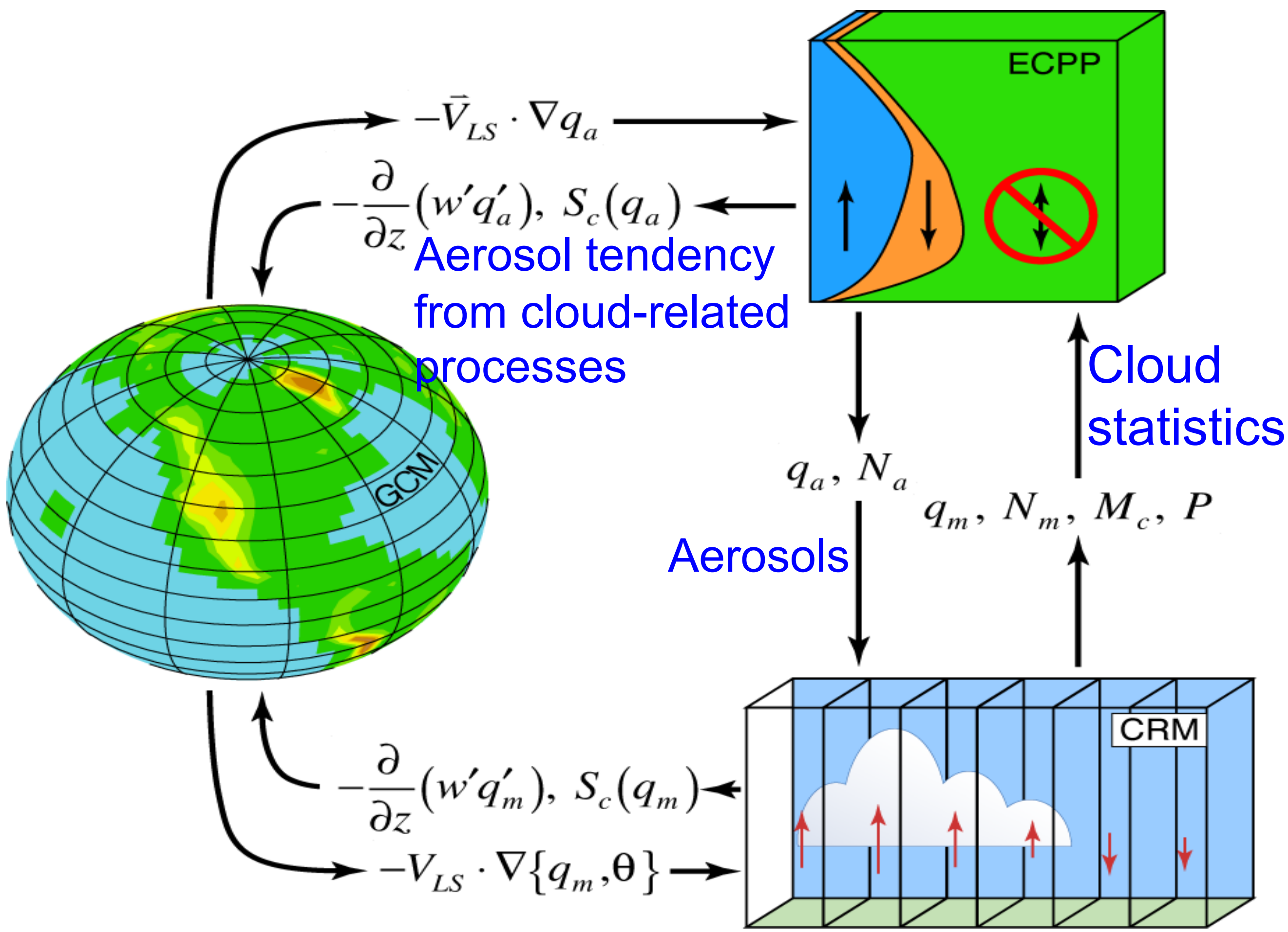
- No aerosol and chemical processes.
- Bias in boundary layer clouds.
- Oversimplified microphysics in CRM.

The original MMF was extended to treat aerosol cloud interactions for the first time



Explicit clouds Parameterized Pollutants (ECPP) Approach (Gustafson et al., 2008)

Use cloud statistics to drive a physically-based treatment of aerosol and trace gas processing by clouds, which replaces conventional treatment of these processes in CAM5.



Model configuration

MMF:

- GCM component: NCAR CAM5

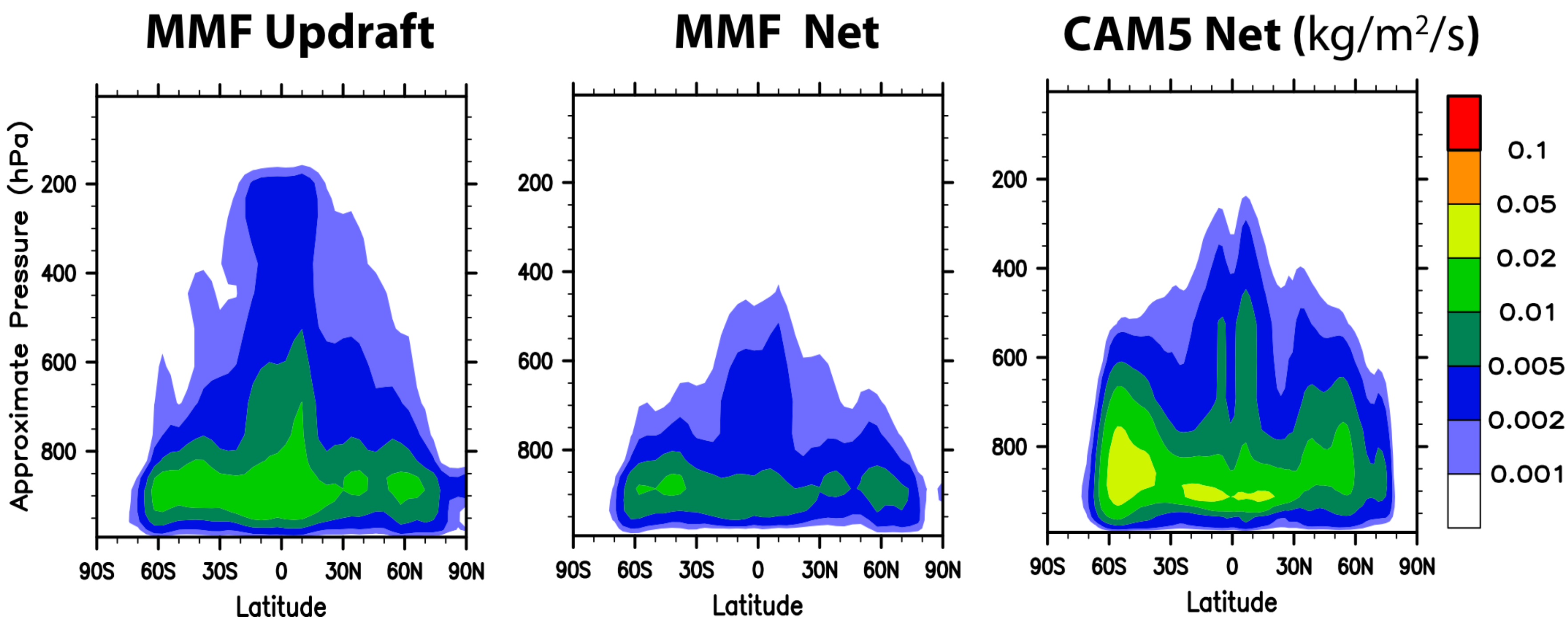
  - finite volume dynamical core;
  - fixed SST and sea ice;
  - 10 minutes time step;
  - IPCC AR5 emissions (present day and preindustrial emissions);
  - 4x5 horizontal resolution and 30 vertical levels.

- CRM component: SAM

  - 32 CRM columns at 4 km resolution.
  - 20 seconds time step;
  - two-moment Morrison microphysics;
  - high-order turbulence scheme is turned off.

Conventional CAM5 : 1.9x2.5 horizontal resolution

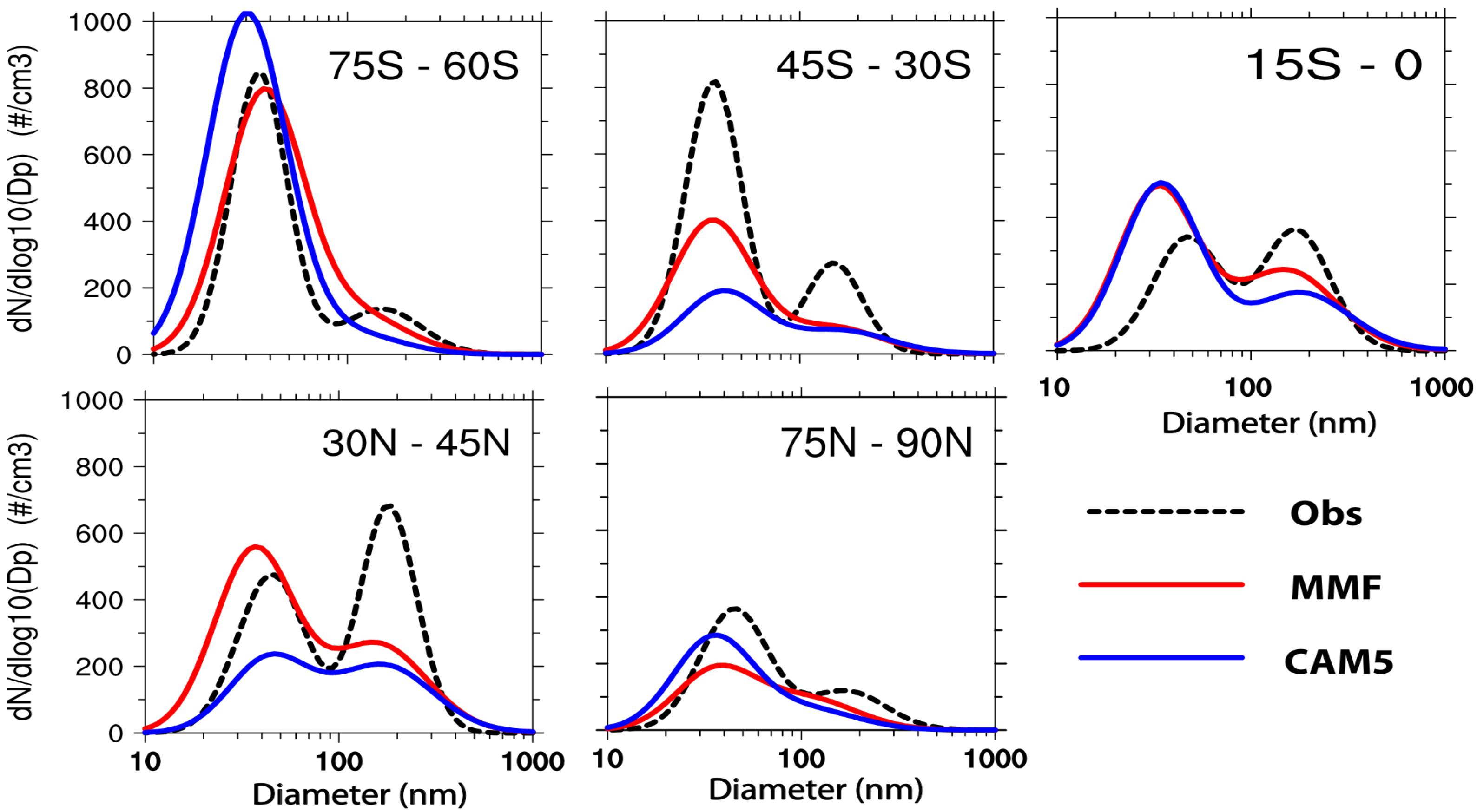
Simulated Convective Mass fluxes



MMF produced

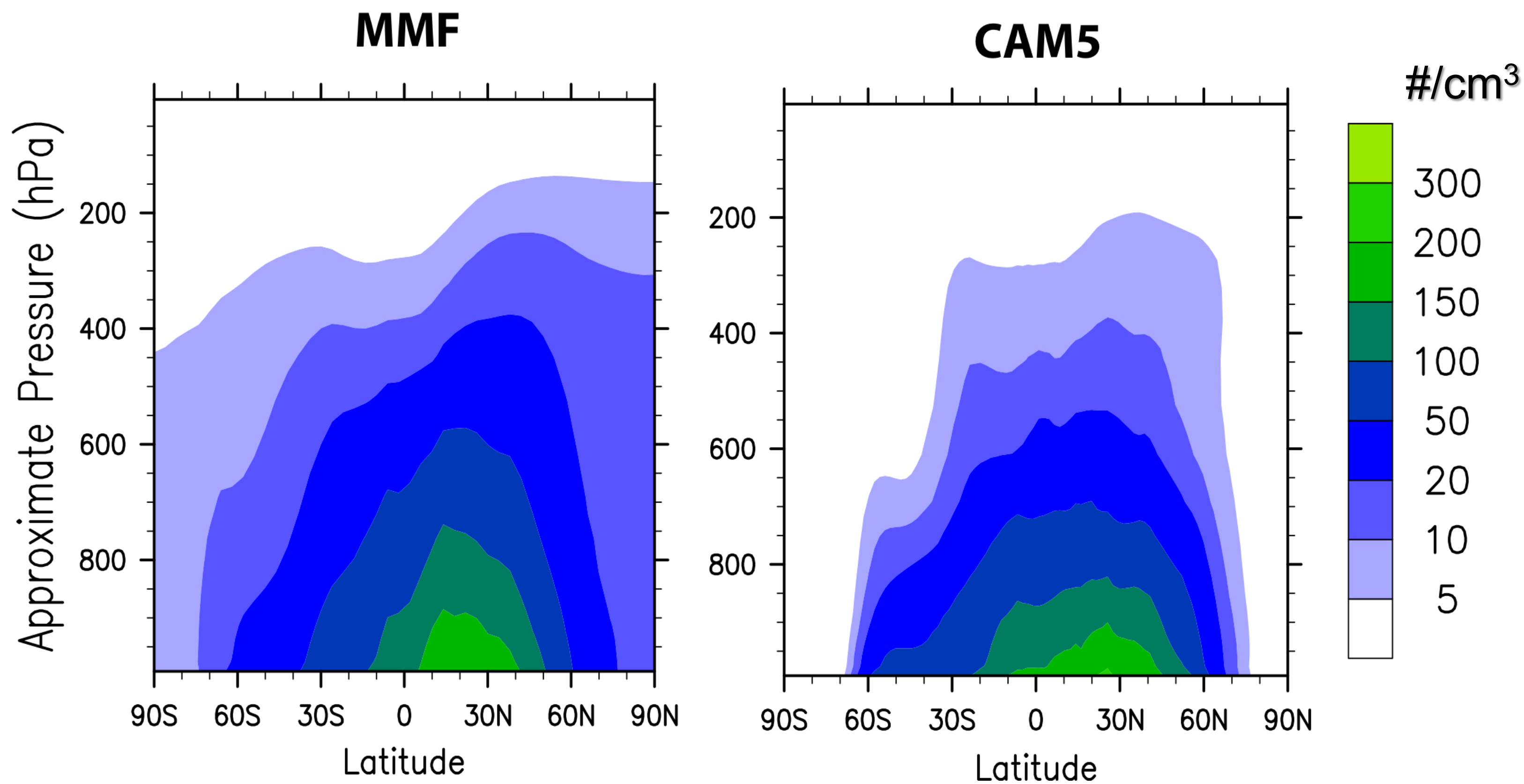
- ➢ weaker net convective mass fluxes.
- ➢ weaker convective updraft mass fluxes at lower levels (< 800 hPa).
- ➢ stronger convective updraft mass fluxes in the upper troposphere.

Aerosol size distributions in the marine boundary layer (Observations: Heintzenberg et al., 2001)



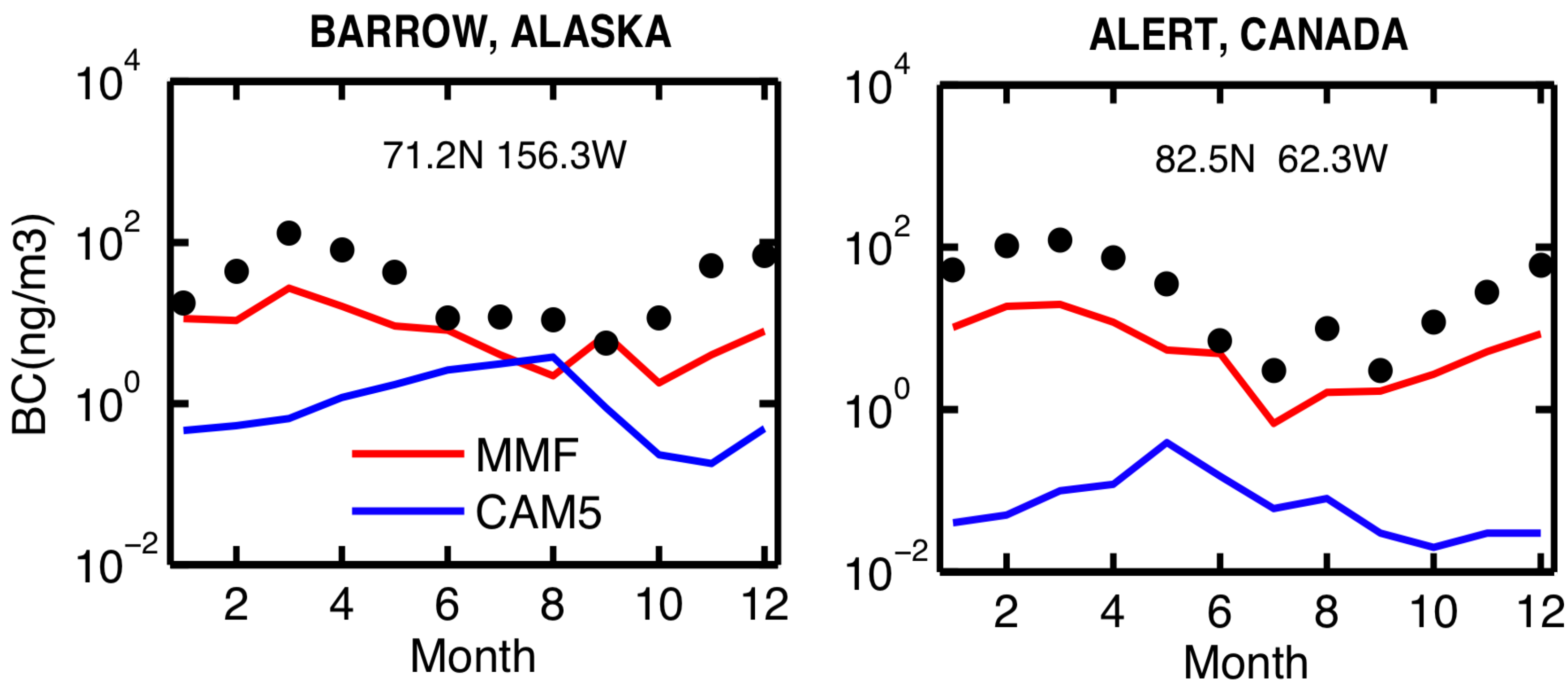
MMF results are similar with those in CAM5, and both are in reasonable agreement with observations.

CCN concentration at 0.1% Supersaturation



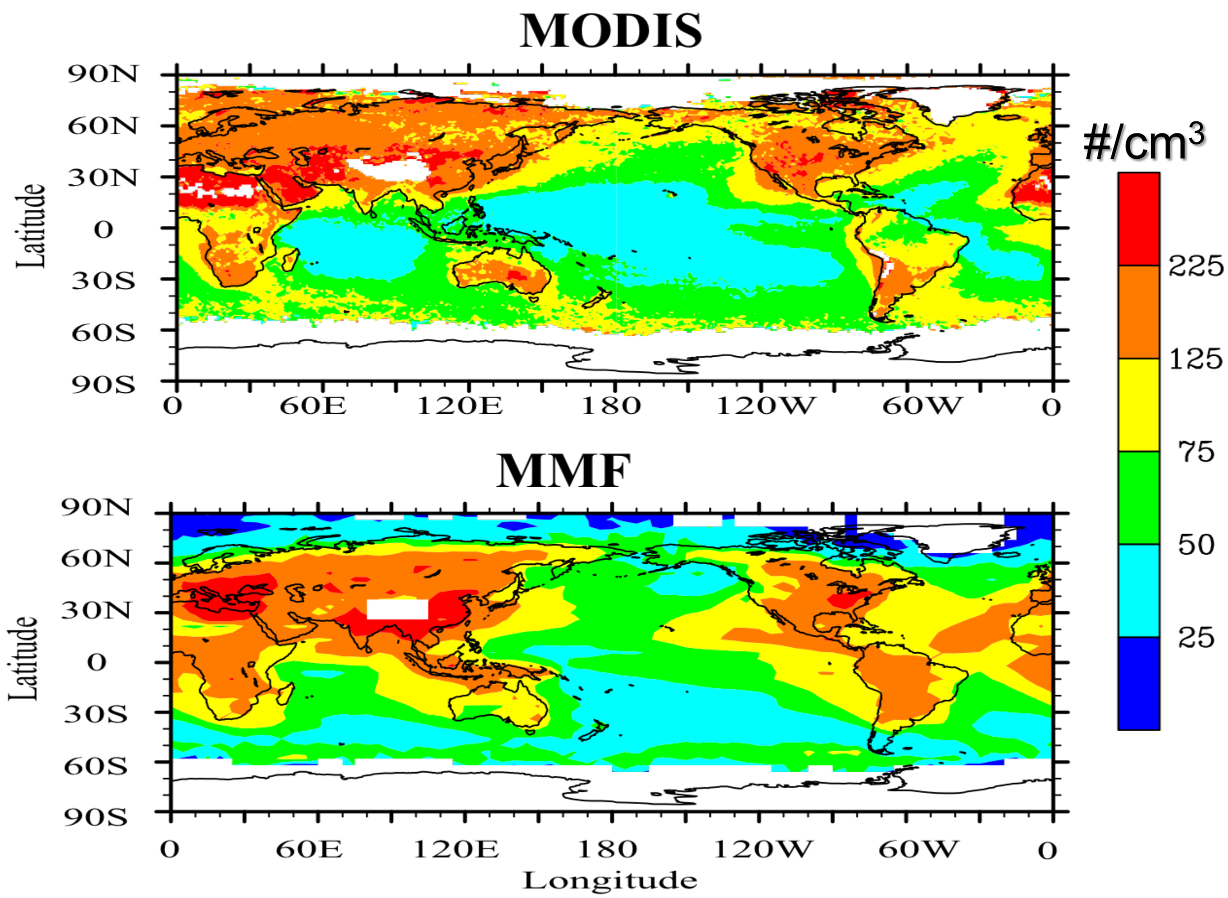
MMF predicts more CCN in the upper troposphere, and at high latitudes.

Monthly BC concentrations in the Arctic



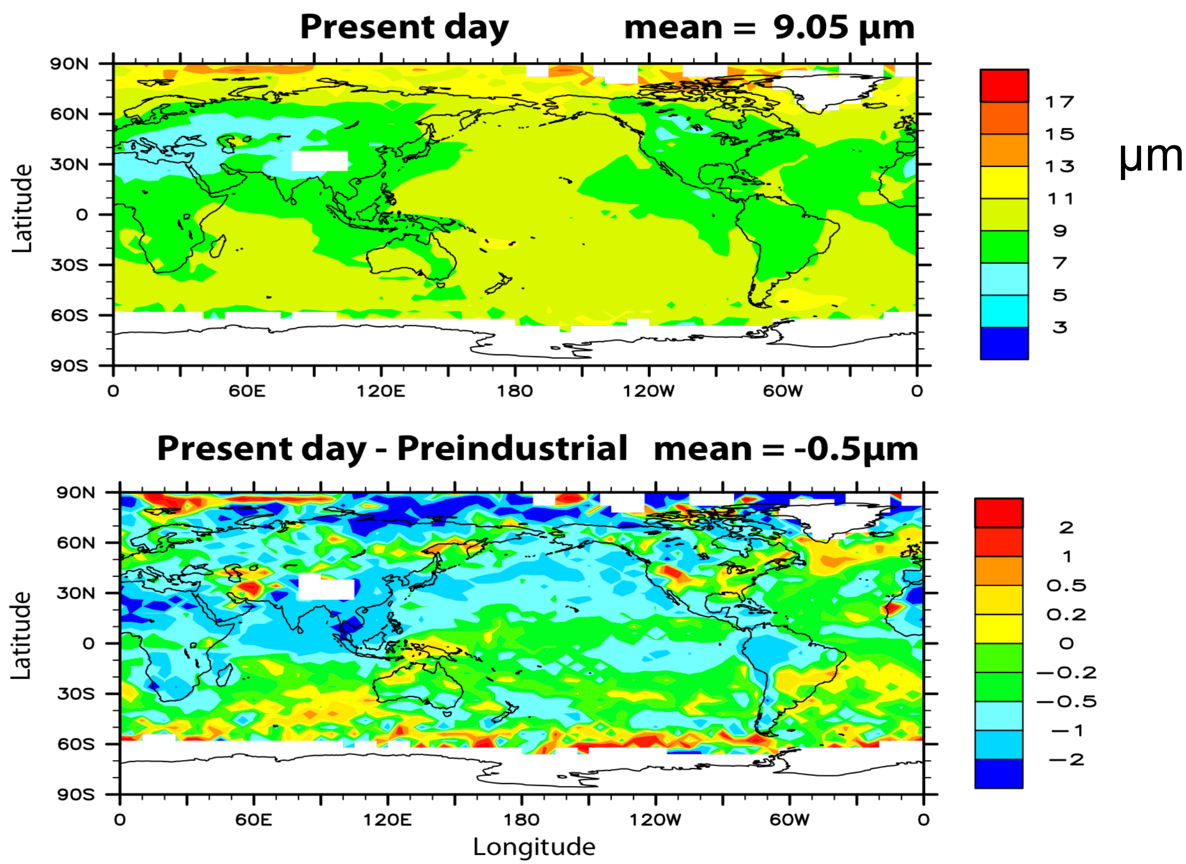
- BC concentrations in MMF agree better with observations.
- MMF simulates the right seasonal cycle

Cloud top droplet number concentration (warm, low level, and liquid clouds only)



MMF simulates ocean/land contrast that is in reasonable agreement with observations.

Cloud top droplet effective radius



Anthropogenic aerosols decrease droplet effective radius, with larger decreases over land than over ocean, over the NH than over the SH.

Anthropogenic aerosol effects

	MMF (PD)	MMF (PD-PI)	CAM5(PD)	CAM5(PD–PI)
AOD	0.139	0.025	0.136	0.019
LWP (g/m^2)	55.66	1.81	48.38	3.93
CLDTOT (%)	56.17	0.17	62.66	0.17
SWCF(W/m^2)	-46.91	**-0.99**	-50.09	**-1.79**
LWCF (W/m^2)	22.33	**0.04**	21.88	**0.37**

PD: present day; PI: preindustrial
AOD: aerosol optical depth; LWP: liquid water path;
CLDTOT: total cloud fraction;
SWCF: shortwave cloud forcing; LWCF: longwave cloud forcing

Simulated aerosol indirect forcing is -1 W/m^2, and is in the range of other model studies and those derived from observations.

Summary and future work

- Aerosol cloud interactions are simulated in a multiscale aerosol climate model for the first time.
- Simulated aerosols and clouds are in reasonable agreement with observations.
- Simulated aerosol indirect forcing is -1 W/m^2, and is in the range of other model studies and those derived from observations.
- Future work will focus on examining the relationship between aerosols and clouds from both models and observations.
- The high-order turbulence scheme will be included in the future study of aerosol/cloud interactions.

Low level cloud fraction