Multiscale Modeling of Aerosol Effects on Climate

Minghuai Wang, Richard Easter, Mikhail Ovchinnikov, William Gustafson, Steve Ghan, Yun Qian, Evgueni Kassianov, and Xiaohong Liu (PNNL)
Vince Larson and Dave Schanen (U. Wisconsin-Milwaukee)
Hongbin Yu (U. Maryland – Baltimore County)
Hugh Morrison (National Center for Atmospheric Research)
Marat Khairoutdinov (State U. New York – Stonybrook)

The Challenge

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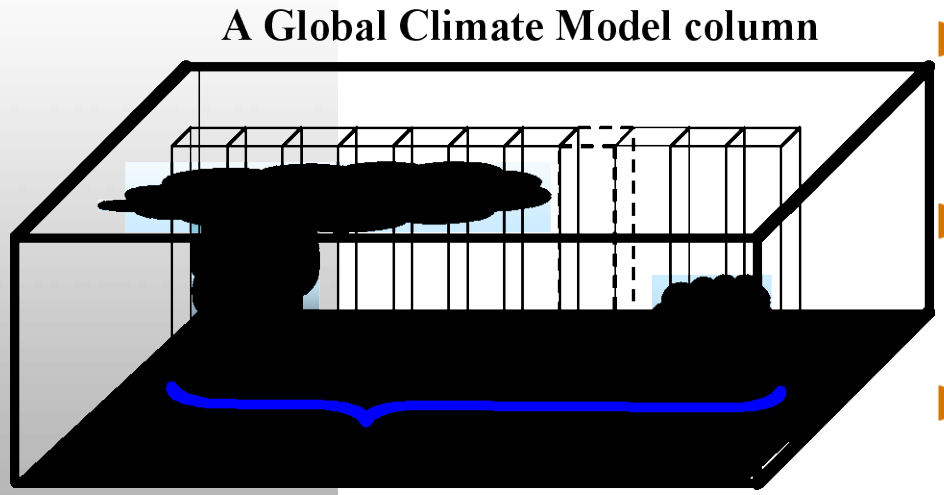
- Clouds form on spatial scales far smaller than the Earth, but produce a large net impact on the global energy balance.
- Aerosol particles influence cloud formation.
- Clouds transport, process, and scavenge the aerosol.
- Previous global estimates of anthropogenic aerosol effects on clouds have neglected aerosol effects on cumulus clouds.

A Computationally Intensive Solution

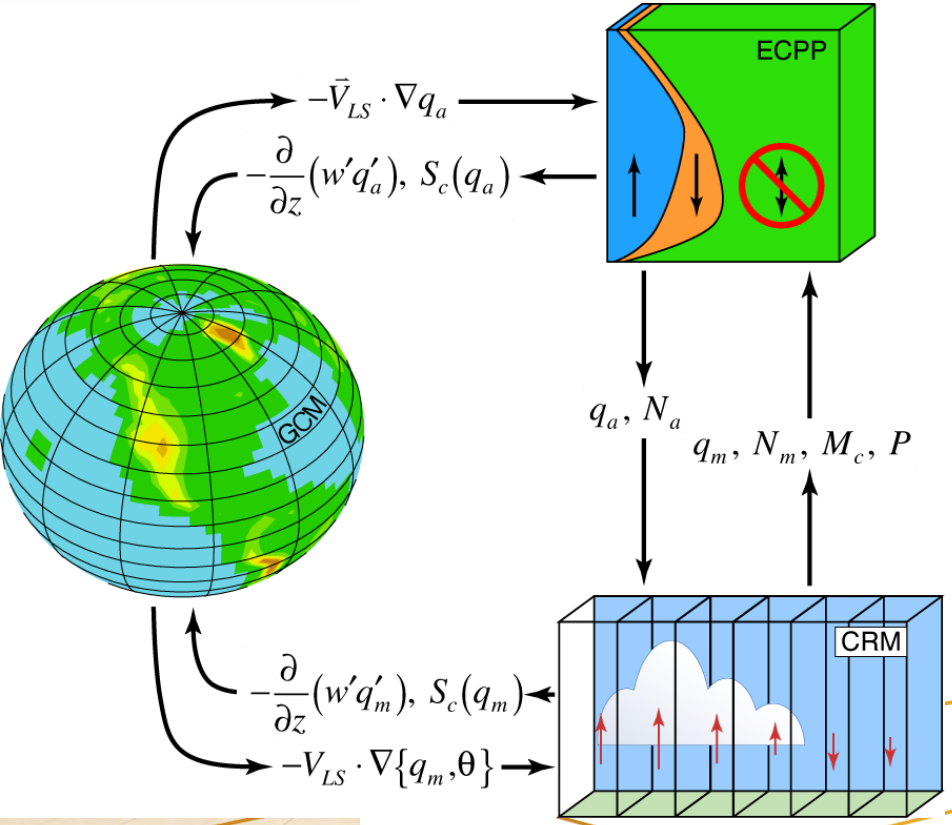


- Embed a cloud-resolving model (CRM) within each grid cell of a global model.
- Embed the aerosol transport, transformation, and removal within the CRMs.
- Predict droplet number within the CRM using aerosol from the CRM.

Is a Computational Monster

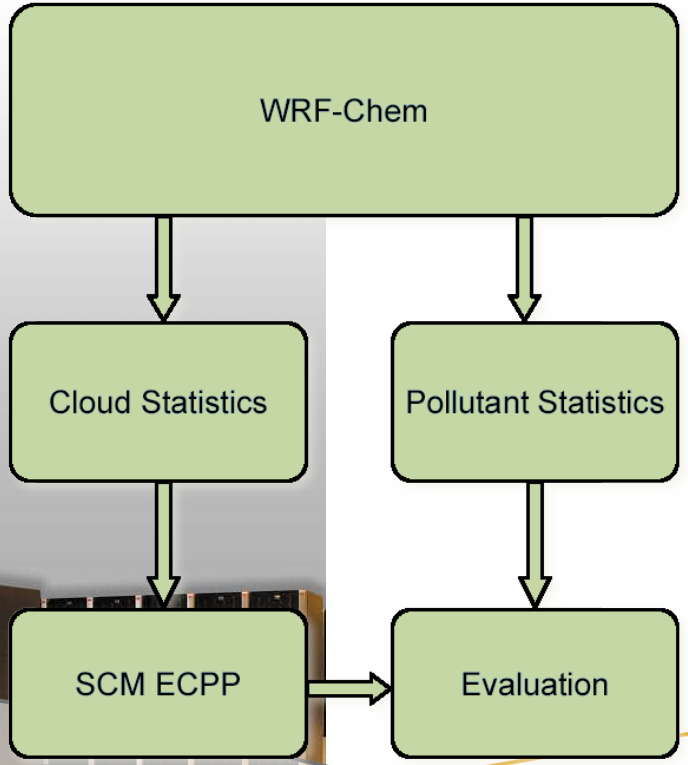
- Such multiscale models require about 200 times the computational resources of global models with conventional cloud parameterizations, *even without treating cloud-aerosol interactions*.
- Plans for future multiscale simulations will cost even more:
  - Six-fold for Δx=1 km instead of 4 km
  - Three-fold for quasi-3D on geodesic grid
  - Hundred-fold for full 3D
- Chemistry and aerosol physics can cost 2-10 times as much as typical climate physics.
- Adding chemistry and aerosol physics to embedded CRMs would produce a *computational monster*.

An Affordable Solution: Explicit Clouds, Parameterized Pollutants



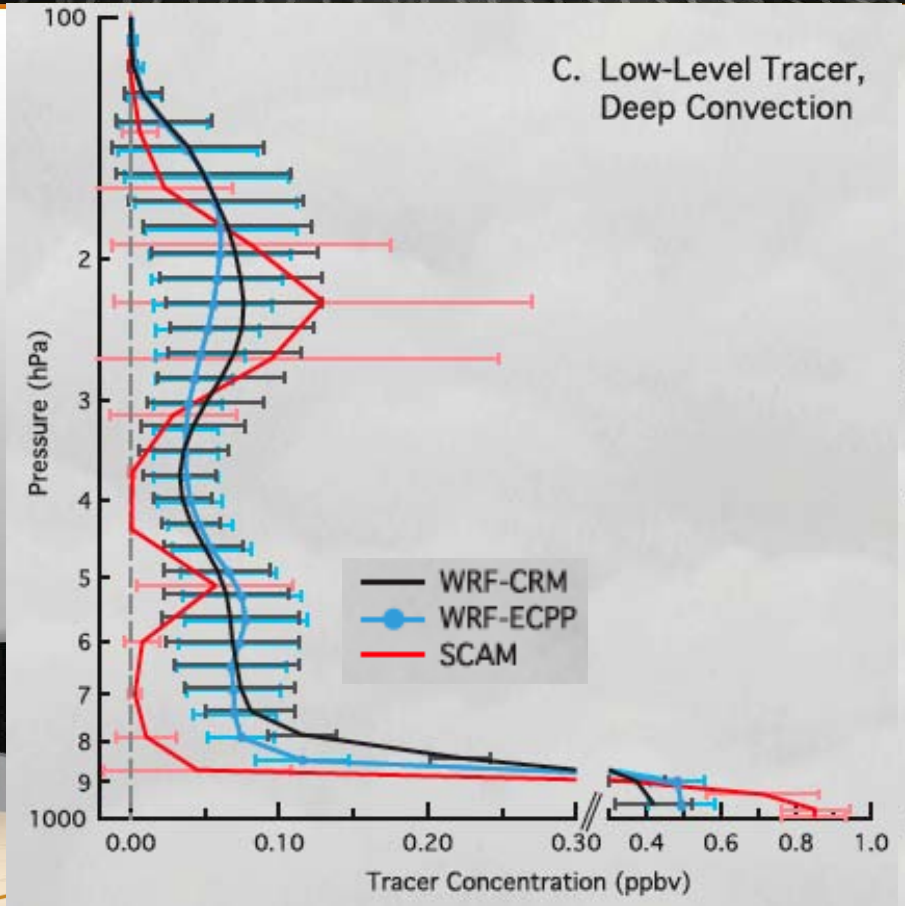
- Predict the aerosol for the outer global grid only.
- Calculate water uptake and scattering/absorption of sunlight on the CRM grid.
- Predict droplet number within the CRM using aerosol from the global model.
- Use subgrid spatial cloud statistics from the CRM to treat vertical transport, transformation, and scavenging of the aerosol by clouds.

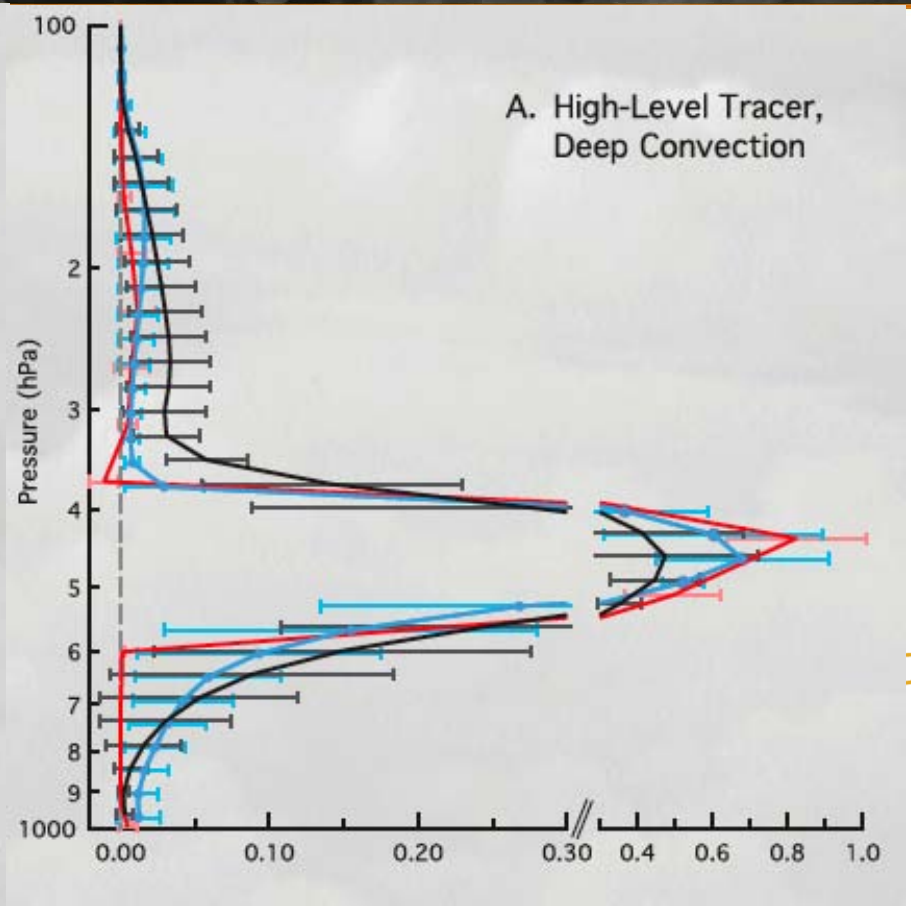
Offline Testing of ECPP



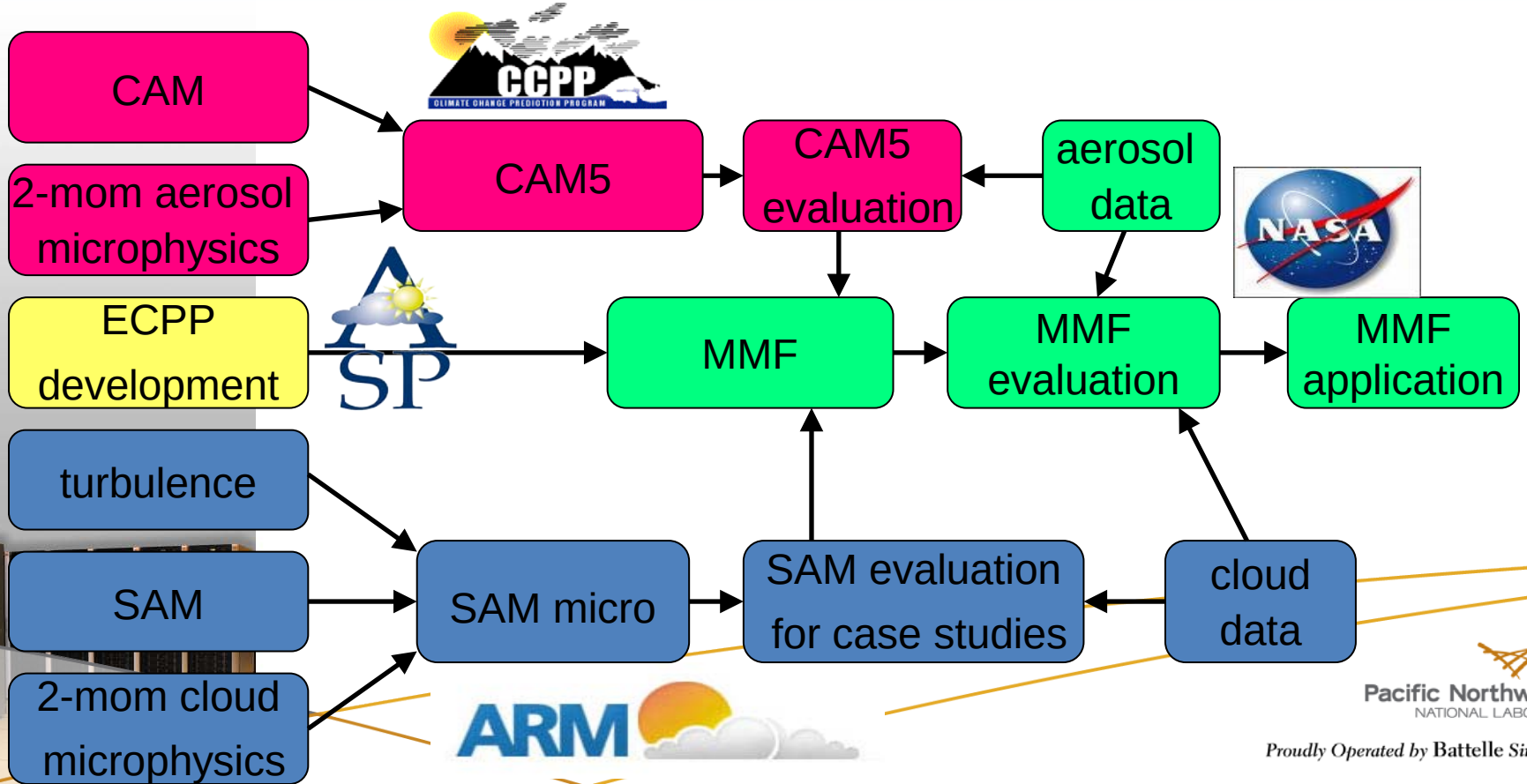
- Perform cloud-resolving pollution simulations with WRF-Chem.
- From model history calculate domain averaged cloud statistics.
- Use cloud statistics to drive a Single Column Model (SCM) with ECPP.
- Evaluate SCM pollutant simulation using domain averaged pollutant statistics from WRF-Chem simulation.

Vertical Transport by Deep Convection





Assembling a Multiscale Modeling Framework

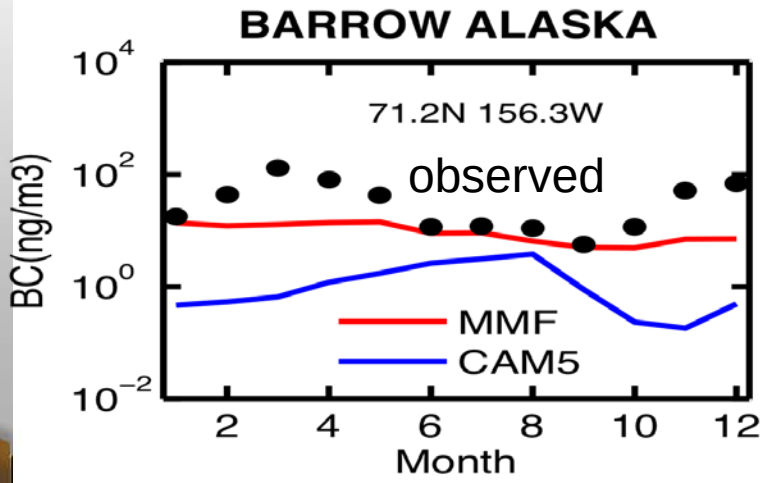


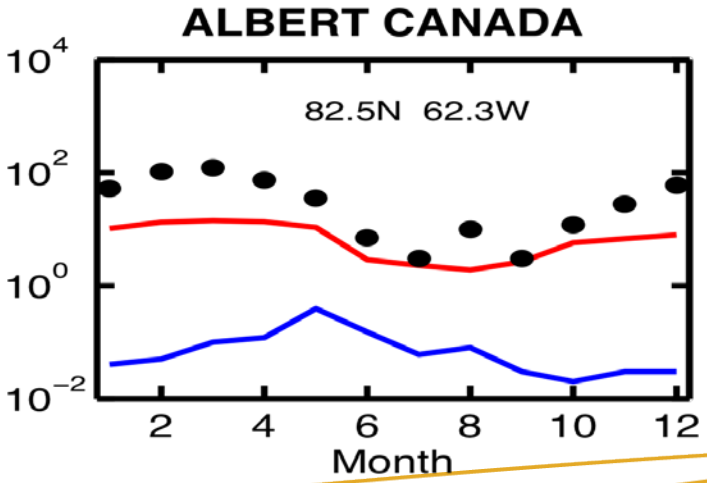
MMF Configuration

- CAM5 General Circulation Model:
  - finite volume dynamical core
  - fixed SST
  - 10 minutes time step
  - IPCC aerosol emissions
  - 1.9°x2.5° horizontal resolution and 30 vertical levels
- SAM Cloud Resolving Model:
  - 32 CRM columns and 4 km resolution
  - 20 second time step
  - two-moment Morrison microphysics
  - high-order turbulence scheme is turned off

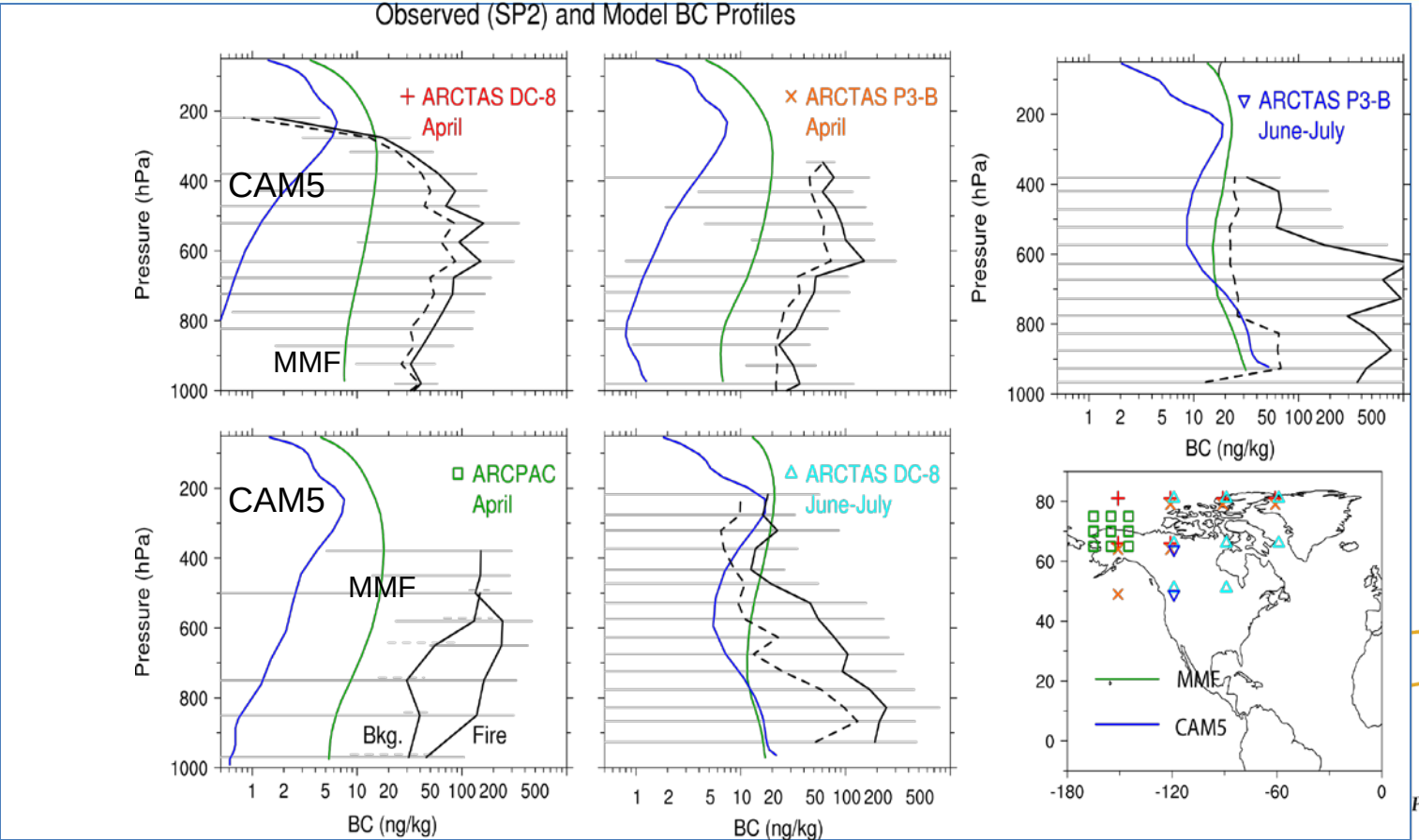
Improvements in Polar Regions

Black Carbon





Black Carbon Improvements Above Surface



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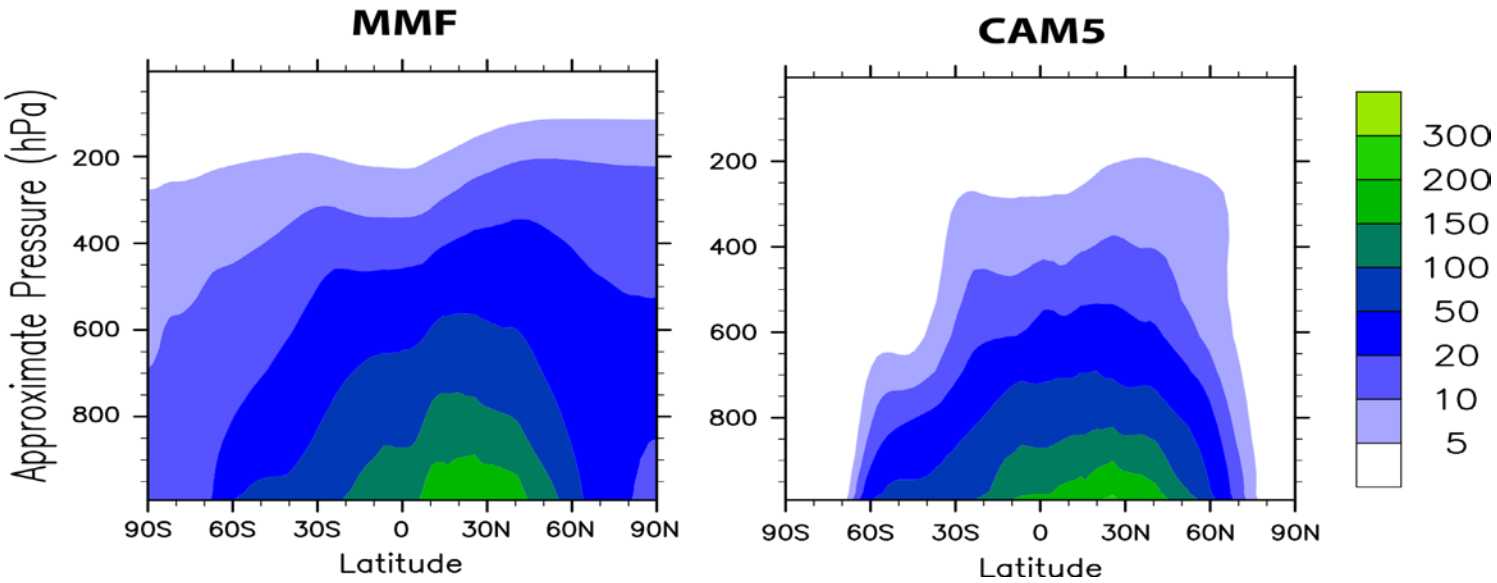
MMF predicts more cloud condensation nuclei

- CCN concentration at 0.1% Supersaturation
- More CCN in the upper troposphere and near poles.



Application: Weaker Aerosol Radiative Forcing

- Perform simulations with (PD) and without (PI) emissions from human activity.
- Contrast the simulations to quantify aerosol direct and indirect effects on the global energy balance.

	MMF (PD)	MMF (PD-PI)	CAM5(PD)	CAM5(PD–PI)
AOD	0.132	0.022	0.136	0.019
LWP (g/m^2)	55.9	2.11	48.38	3.93
CLDTOT (%)	55.79	0.04	62.66	0.17
SWCF(W/m^2)	-50.49	**-0.77**	-50.09	**-1.79**
LWCF (W/m^2)	25.96	**-0.06**	21.88	**0.37**
FSNT+FLNT	2.45	**-1.05**	2.18	**-1.66**

Next Steps

- Test advanced turbulence scheme
- Parallelize I/O
- Quantify radiative forcing by black carbon, sulfate
- Estimate climate sensitivity