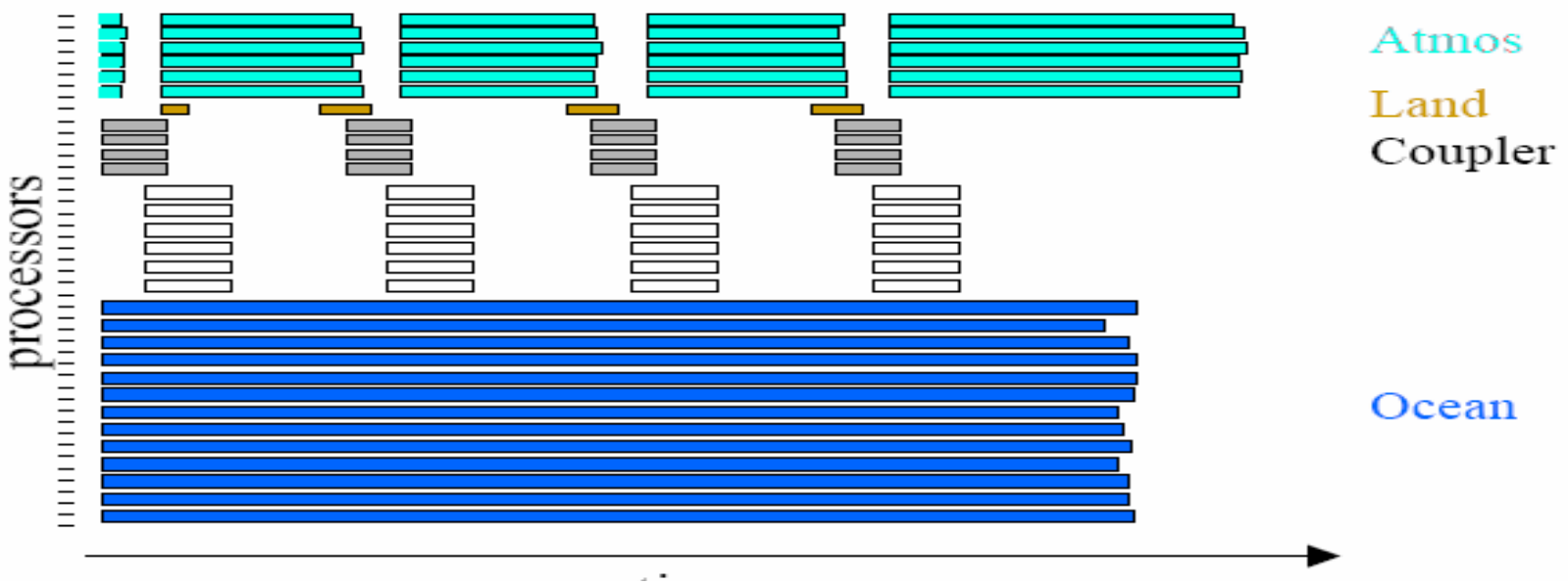
A coupled climate-aerosol model: coupling method and model evaluation

Joyce E. Penner, Minghuai Wang, Xiaohong Liu

University of Michigan

Coupling methods:

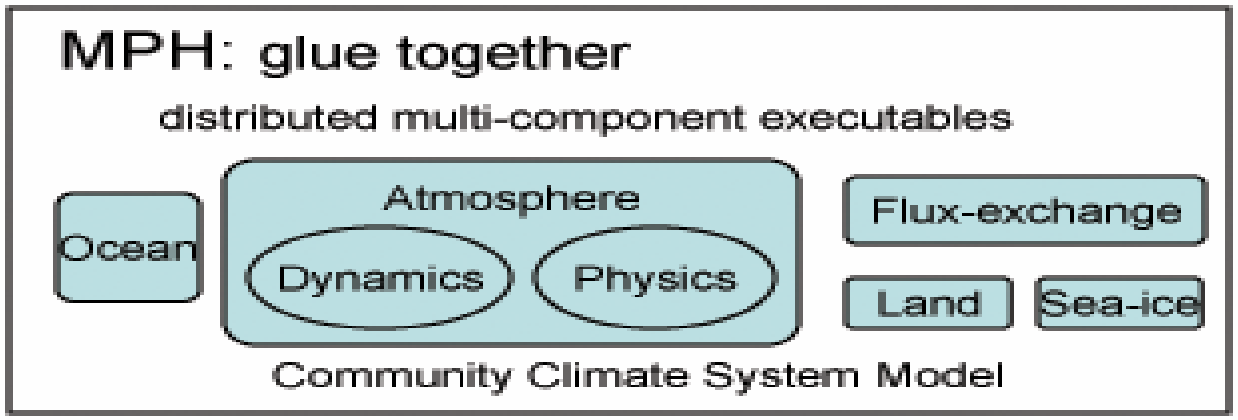
- Code structure: Subroutine vs. Component
- Coupling execution: inside model and outside model.
- Coupler design: Hub and Spokes vs. Tinker Toy.
- Component execution: Sequential vs. Concurrent.



Concurrent execution of the Community Climate System Model

Coupling tools:

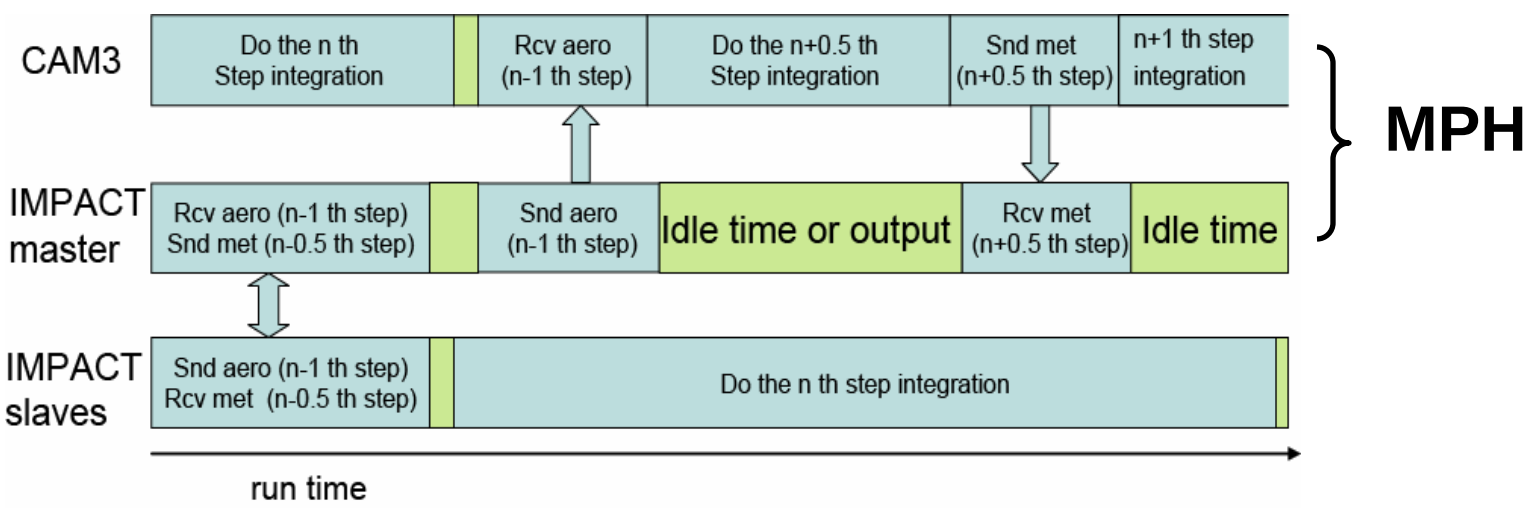
- Earth system modeling Framework (ESMF)
- Model Coupling Toolkit (MCT) – Argonne National Laboratory
- WRF I/O API MCT Coupling Implementation
- Space Weather modeling Framework (SWMF)
- Multi-component Handshaking Library (MPH)-Lawrence Berkeley Laboratory



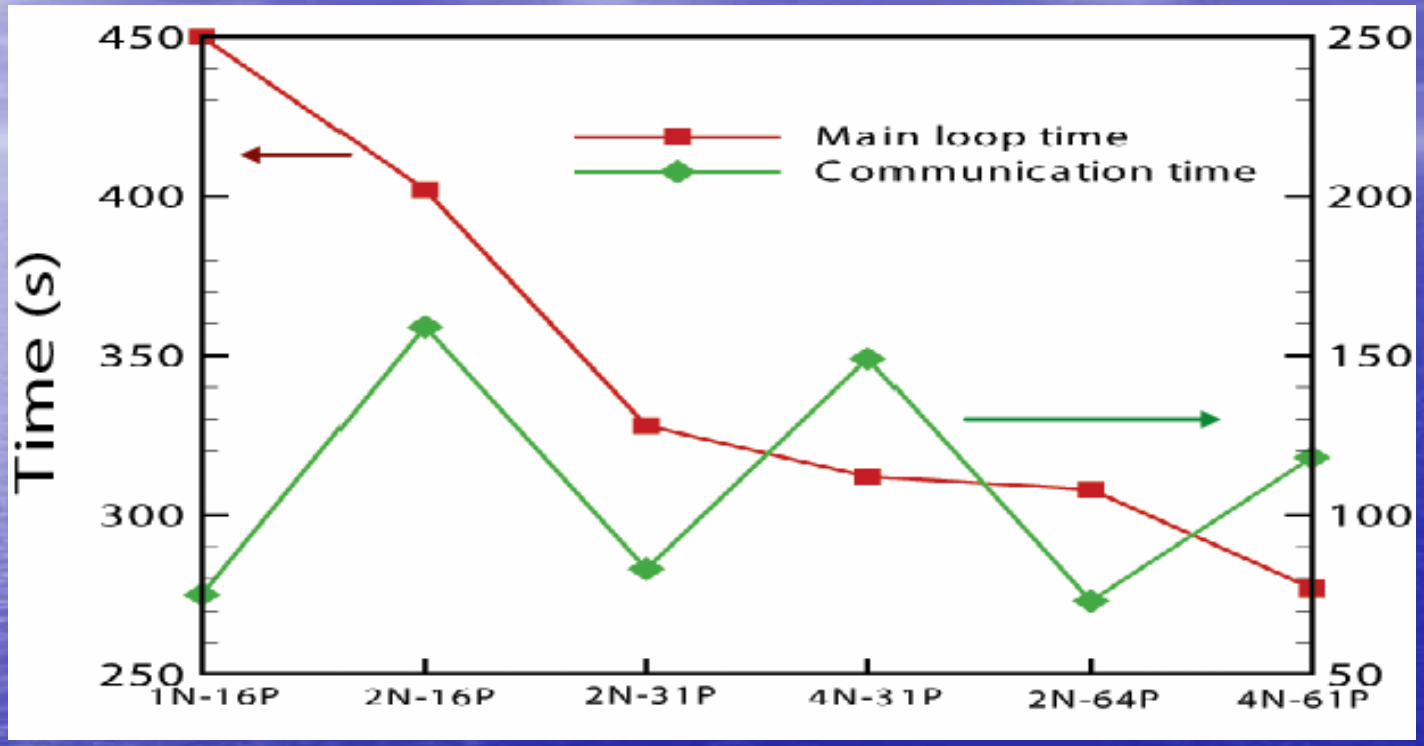
Main functionality

- Component name registration
- Mapping of PEs to components
- Query multi-component environment

Our problem	Implication
The same model resolution, simple variables to exchange	No advanced coupling tools are needed
Massive data communication	Direct communication; No coupler
Different parallel schemes: MPI for IMPACT, MPI/Open for CAM.	Component method; Concurrent execution.
The master processor of IMPACT is used for all input and output.	This master processor can be used as a 'virtual' coupler.
Solution: component code structure, concurrent execution.	



Parallel performance

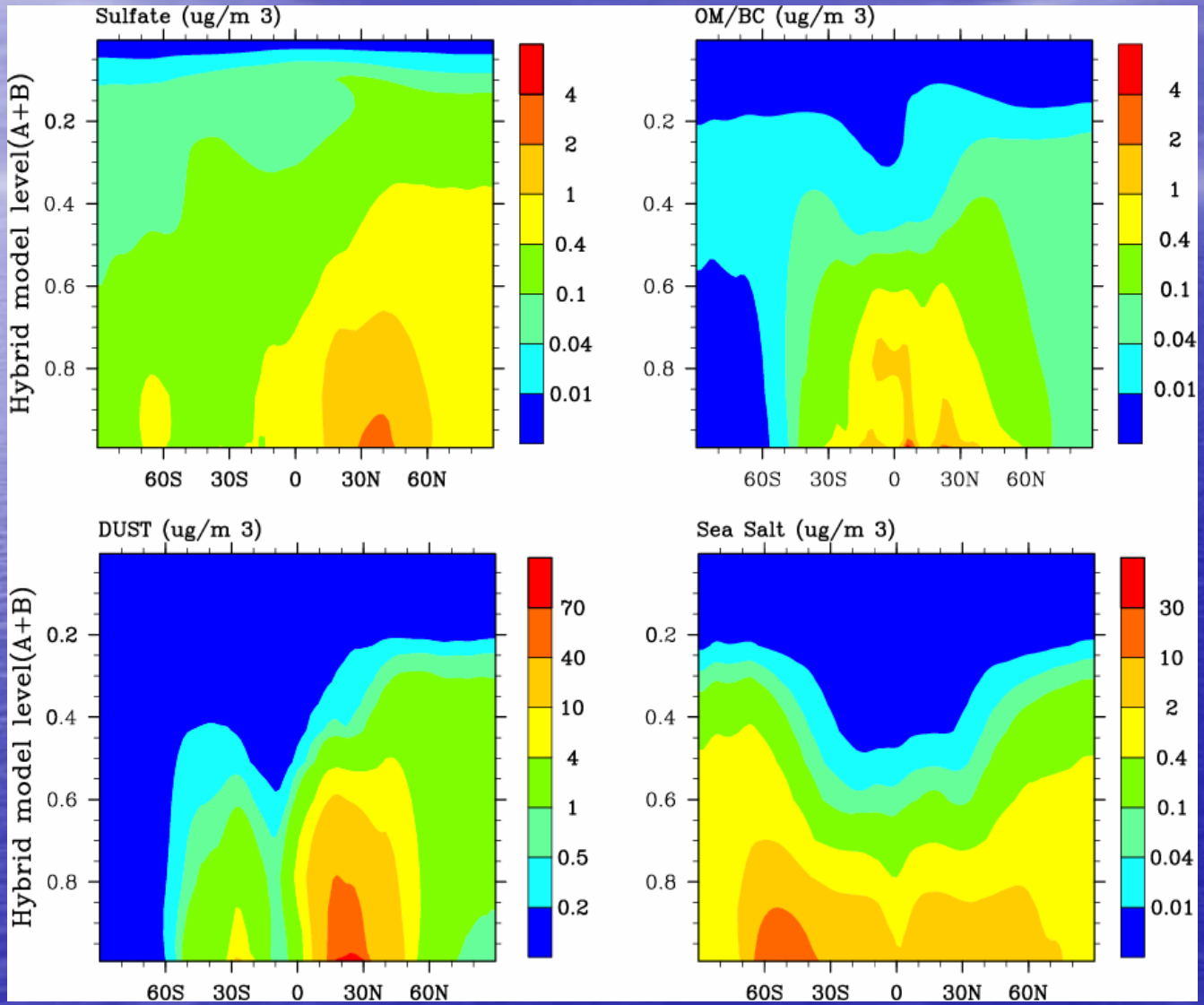


• Three model versions exist: mass only IMPACT, IMPACT with dynamical aerosol module, and IMPACT with nitrate aerosol.

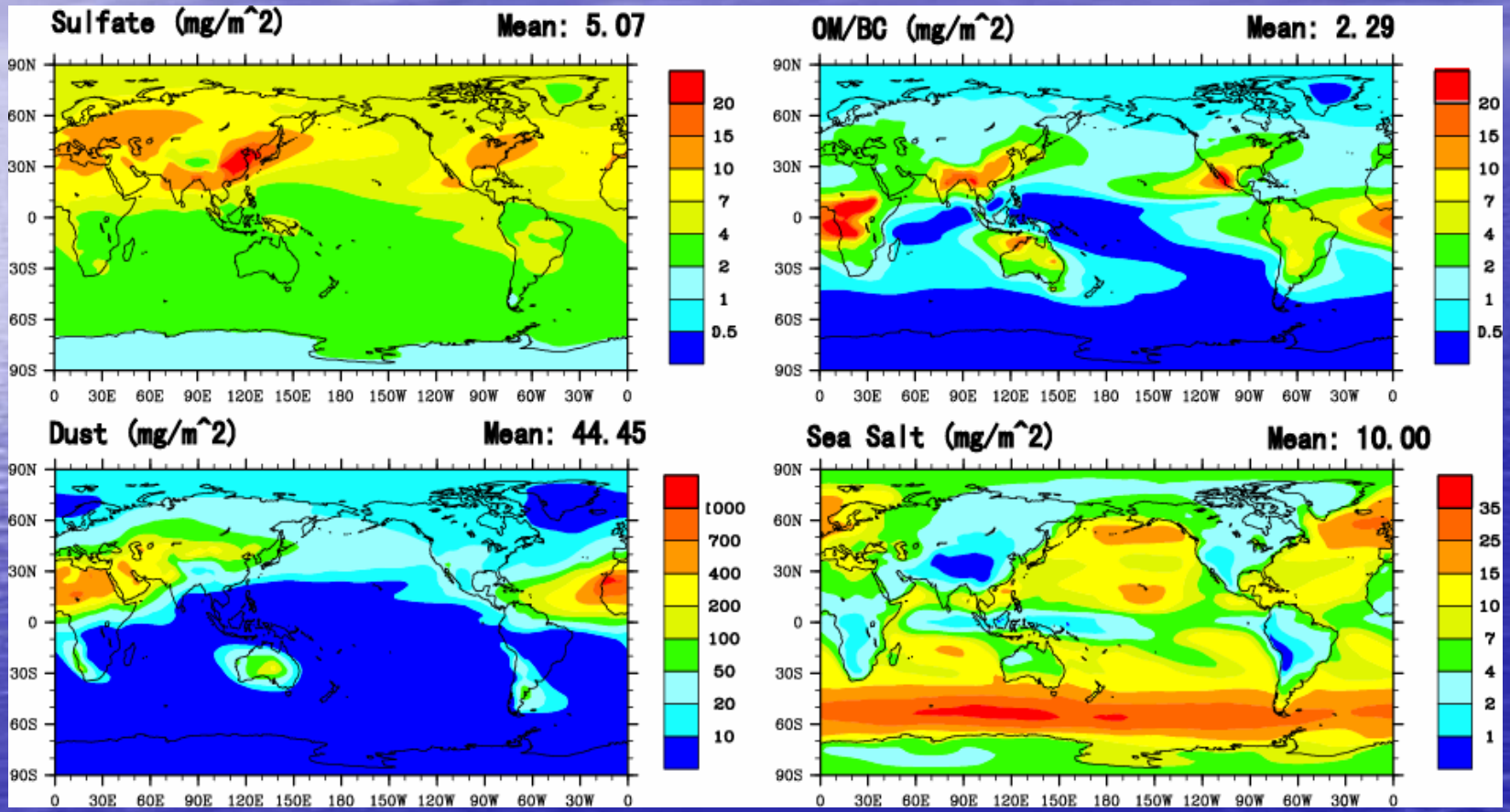
Experiment descriptions:

- The finite-volume dynamical core is used for the CAM3 model. Climatological SSTs are used to force the GCM.
- IMPACT model with aerosol dynamical module is used.
- Emissions of SO_2 are from Smith et al. 2001. DMS emissions are from Kettle and Andreae 2000. Organic matter, black carbon are from Ito and Penner 2005. Dust is from Paul Ginoux.
- Interactive sea salt emissions follow method of Gong et al 1997.
- The model resolution is 2.5*2.0*26 for both the GCM and the aerosol model. The time step is 30 minutes for CAM3 and 1 hour for IMPACT.
- The coupled system was run for 5 years.

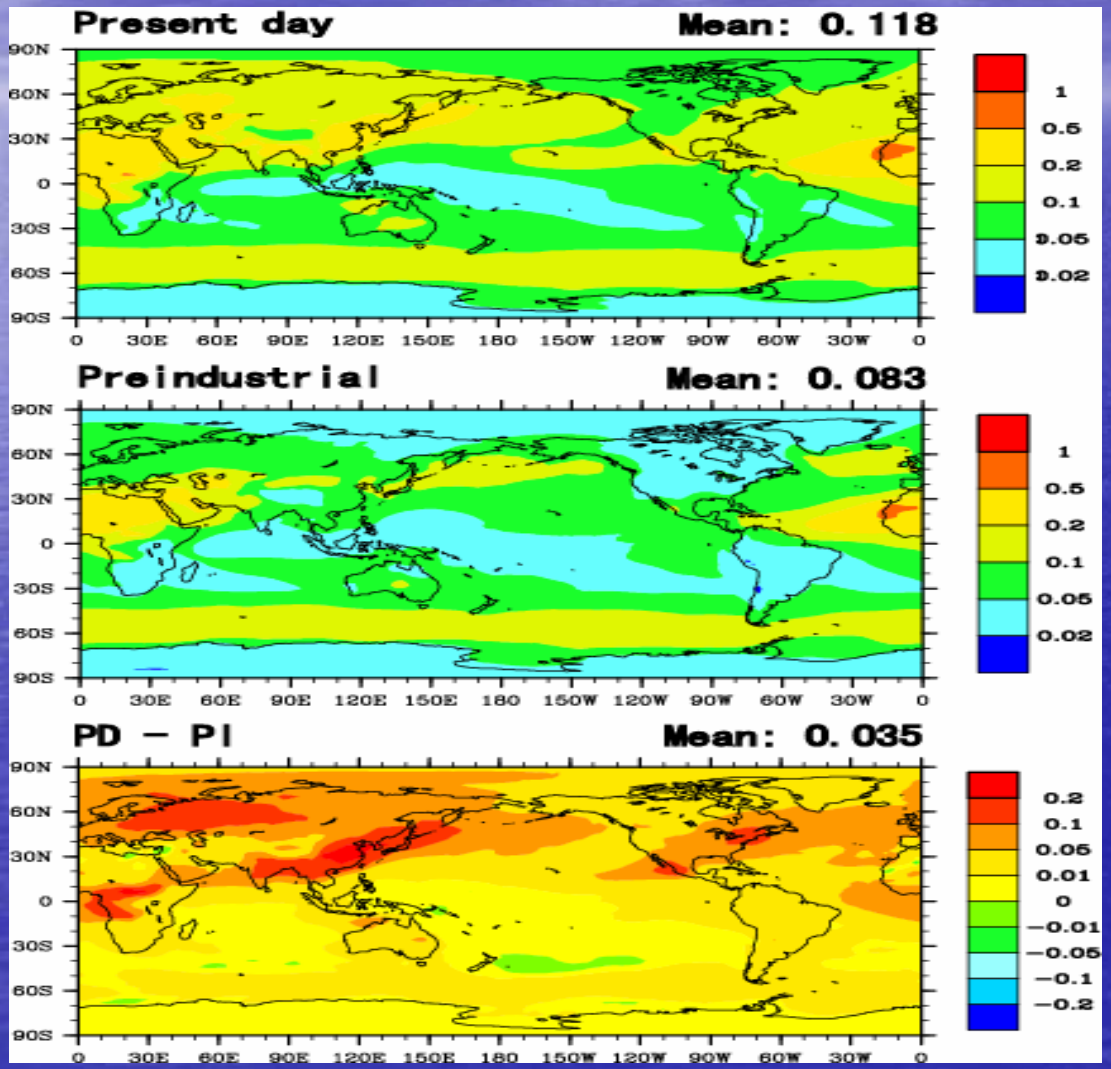
Zonal mean concentration



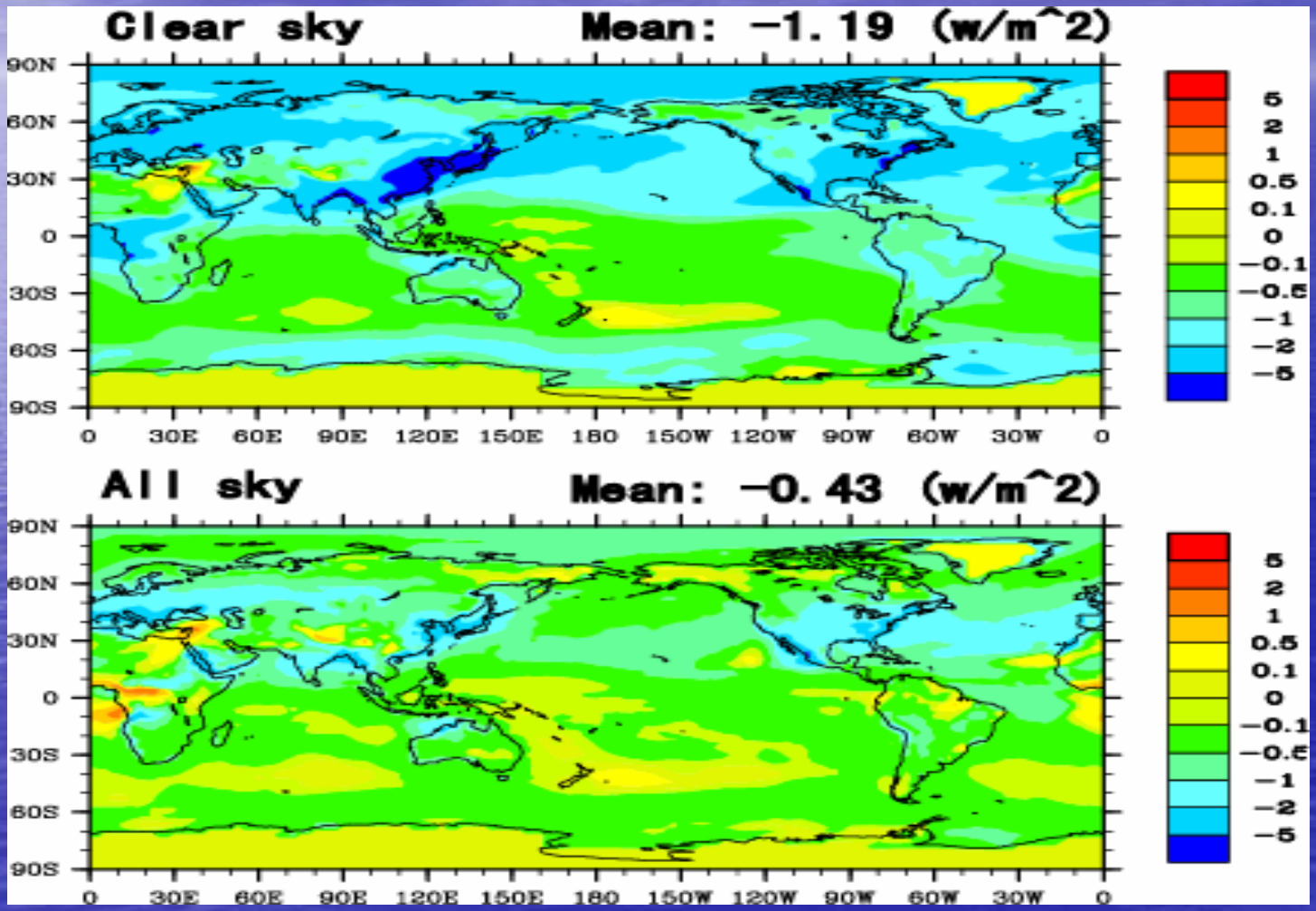
Column burden



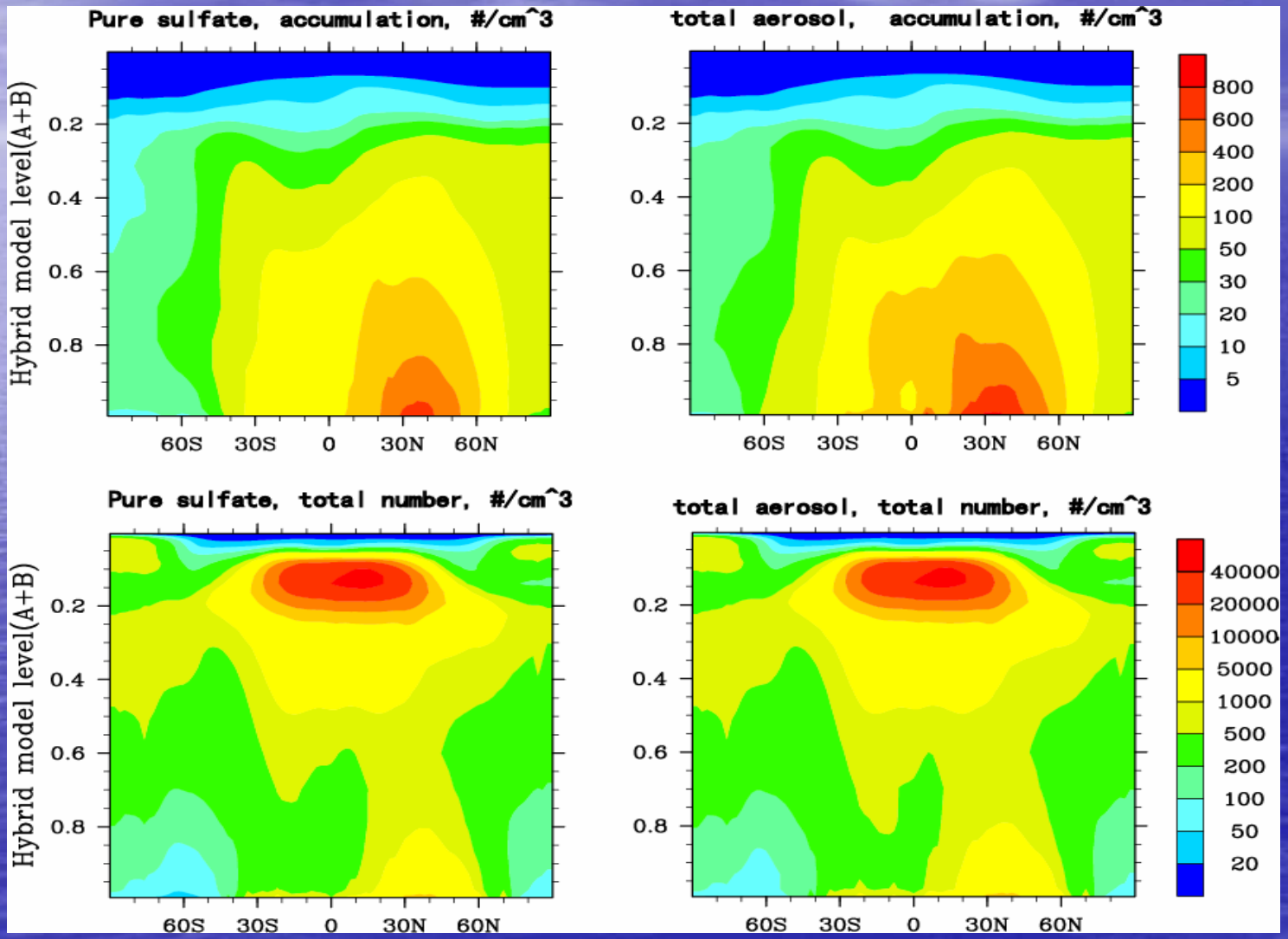
Optical depth at 550 nm



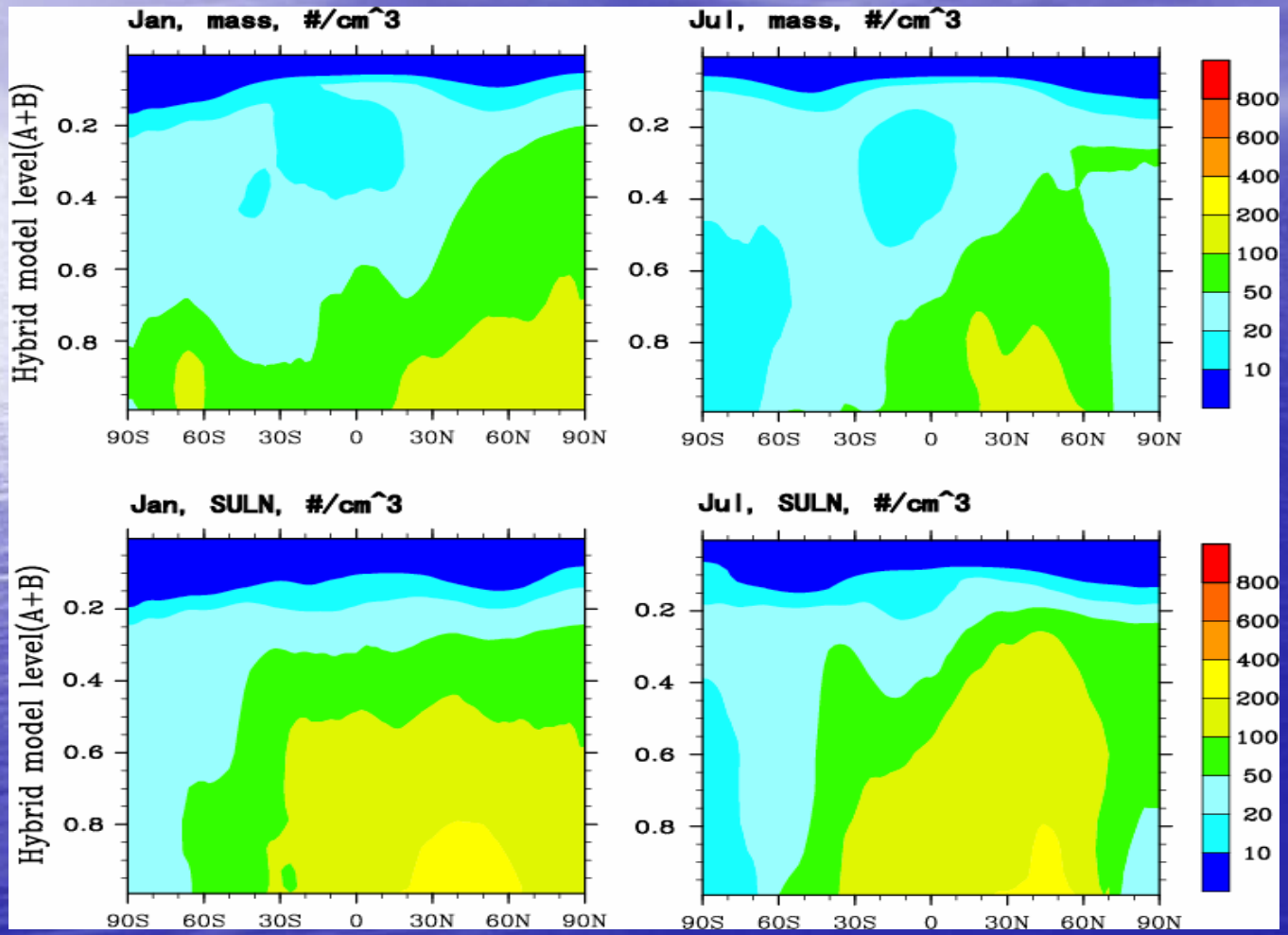
Direct forcing from anthropogenic aerosol



Zonal mean aerosol number



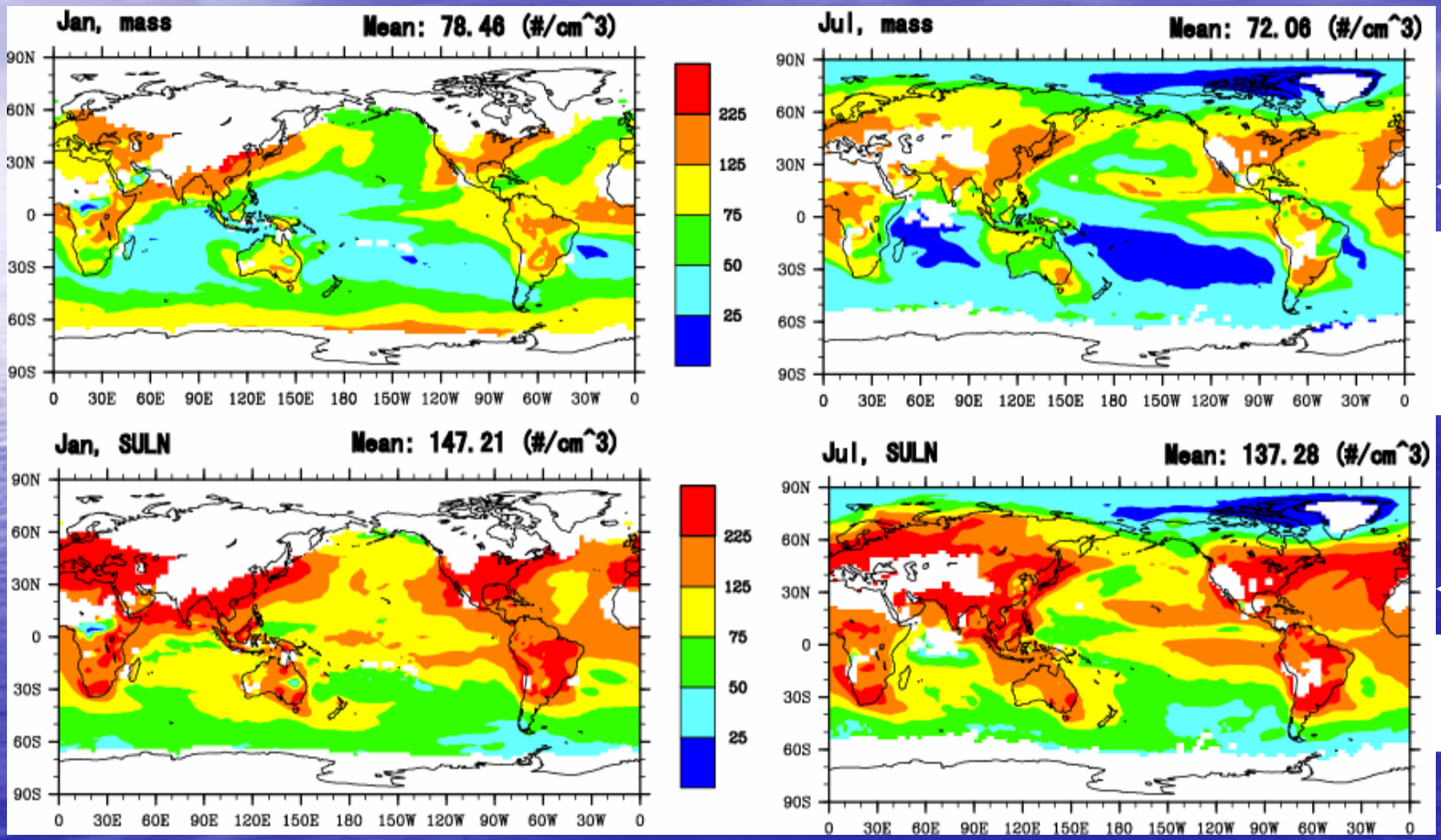
Zonal mean droplet number



Sulfate mass is used with a prescribed size distribution

Sulfate size distribution as predicted

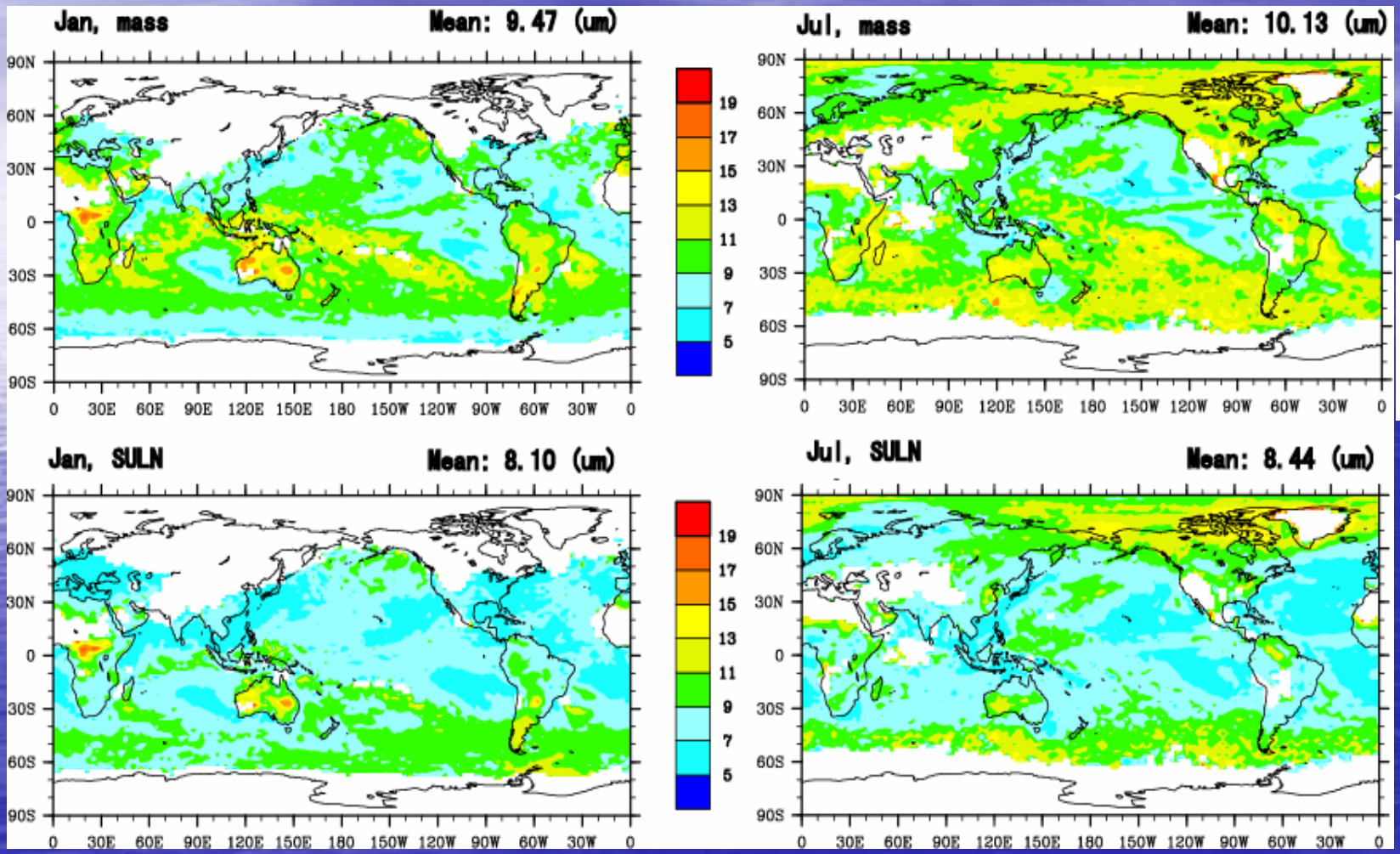
cloud droplet number for warm cloud (ISCCP simulator)



Sulfate mass is used with a prescribed size distribution

Sulfate size distribution as predicted

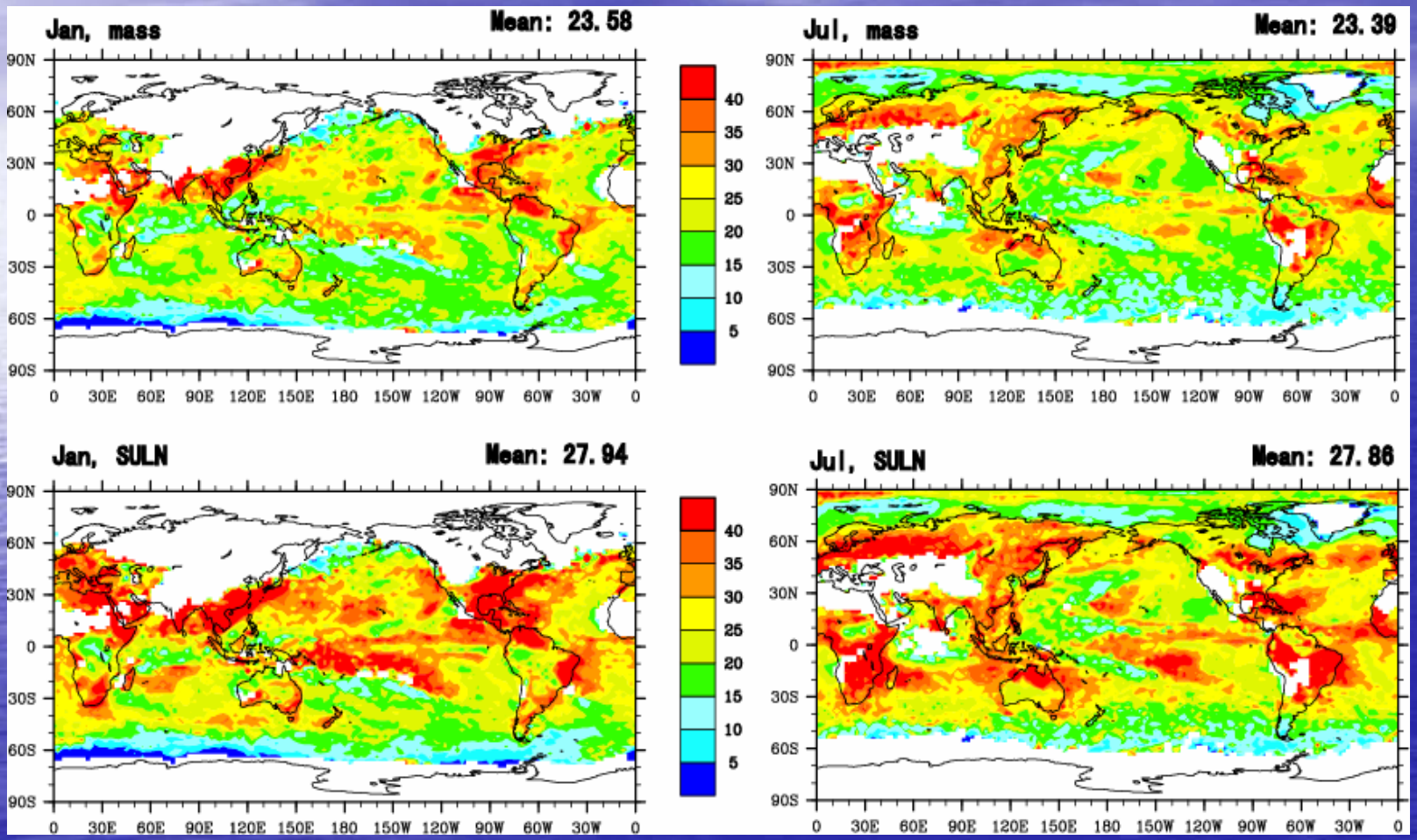
Droplet effective radius for warm cloud (ISCCP simulator)



Sulfate mass is used with a prescribed size distribution

Sulfate size distribution as predicted

Cloud optical depth for warm cloud (ISCCP simulator)



Sulfate mass is used with a prescribed size distribution

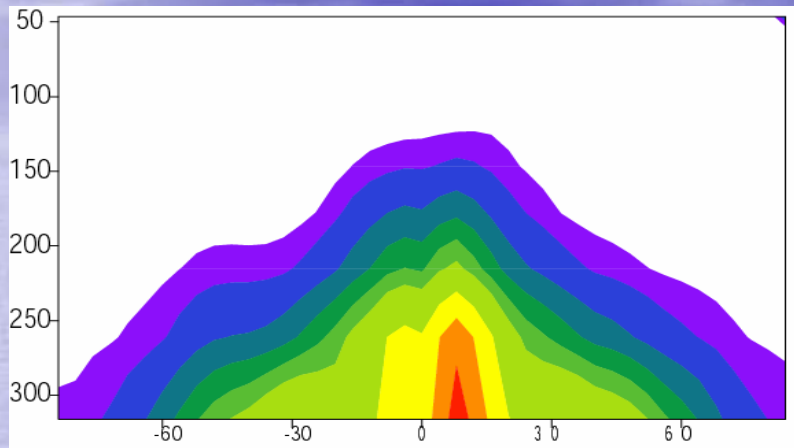
Sulfate size distribution as predicted

Inclusion of Ice Nucleation in NCAR CAM3 (Liu et al., 2007)

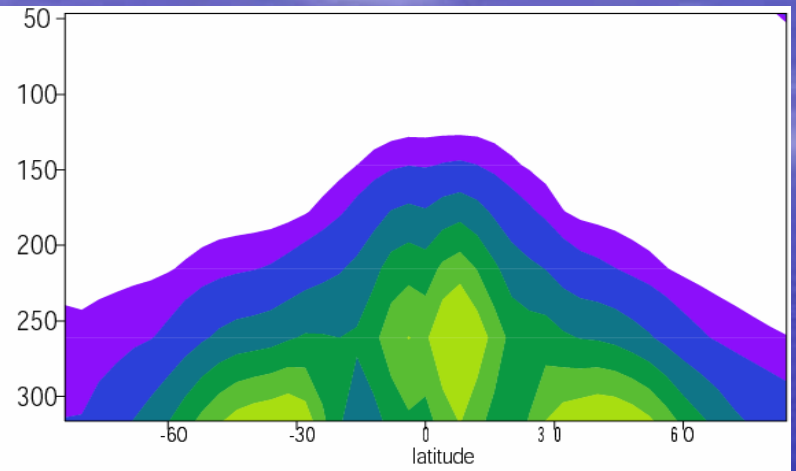
- Implement a prognostic equation for ice number concentration
- Nucleation of ice crystals:
  - ✓ homo. freezing & heter. immersion freezing (T<-35 C) (Liu & Penner, 2005)
  - ✓ Contact freezing of cloud droplets (-35 to 0 C), assuming dust as IN (Young 1974)
  - ✓ Deposition/condensation ice nucleation (-35 to 0 C) (Meyers et al., 1992)
  - ✓ secondary production of ice crystals
- C-E used only for liquid water; allow ice supersaturation
- D_{v2i} : vapor deposition on ice crystals in grid cells (Rotstayn et al., 2000); get rid of $f_{ice}(T)$
- r_{eff} for ice crystals diagnosed from mass & number: number effects on radiation and ice gravitational settling

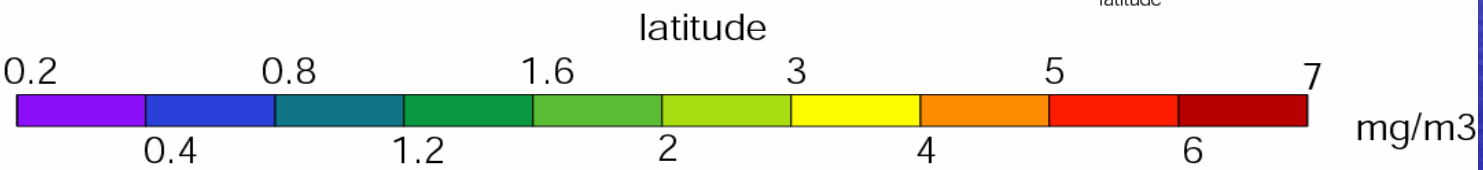
Annual Mean Ice Water Content

Modified CAM

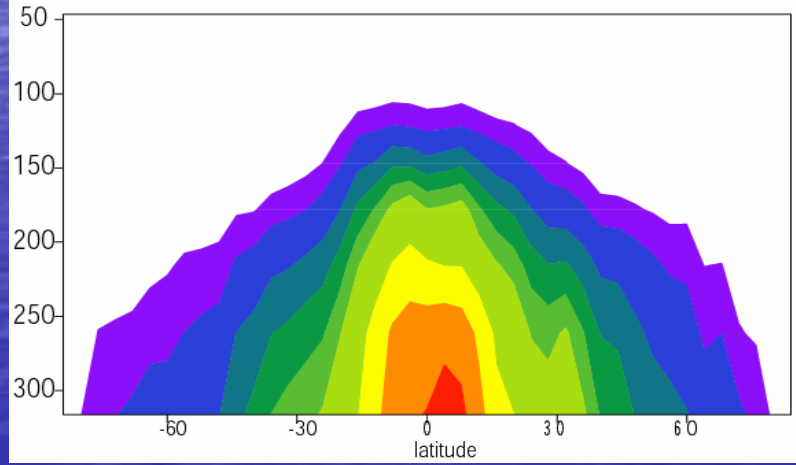


Standard CAM





Aura MLS



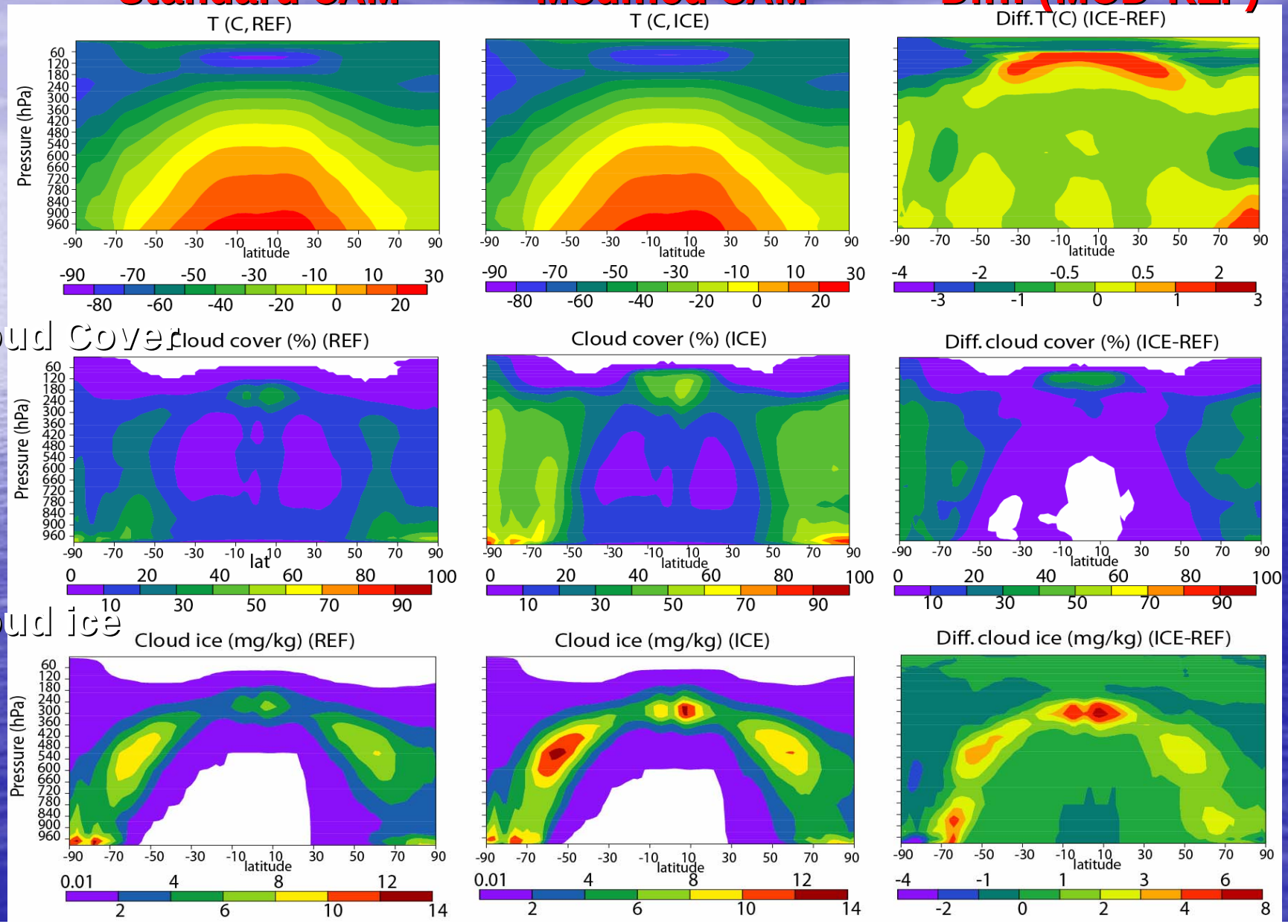
Comparison between standard and modified CAM

Standard CAM **Modified CAM** **Diff. (MOD-REF)**

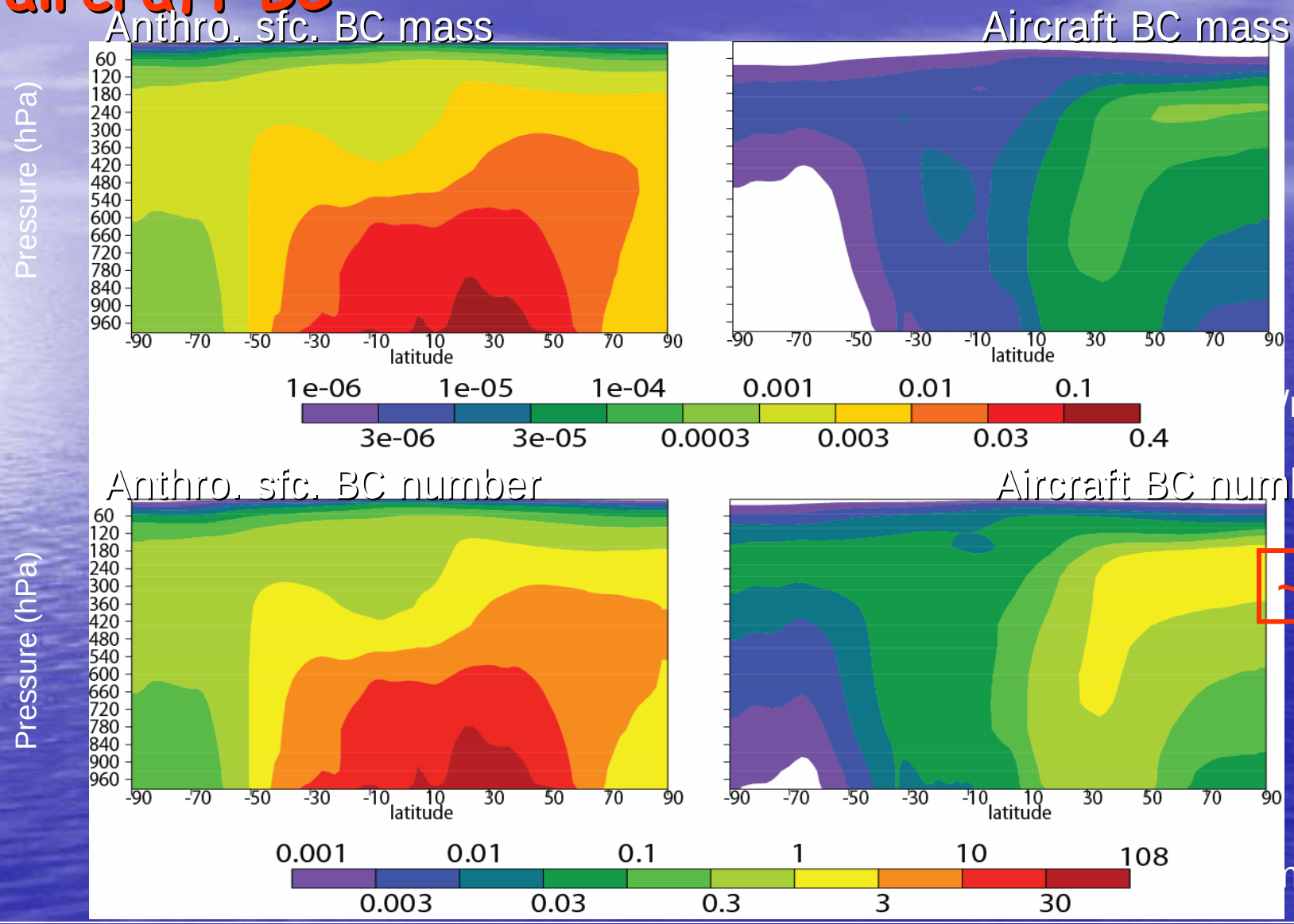
T

Cloud Cover

Cloud ice



Comparison between anthro. surface BC & aircraft BC

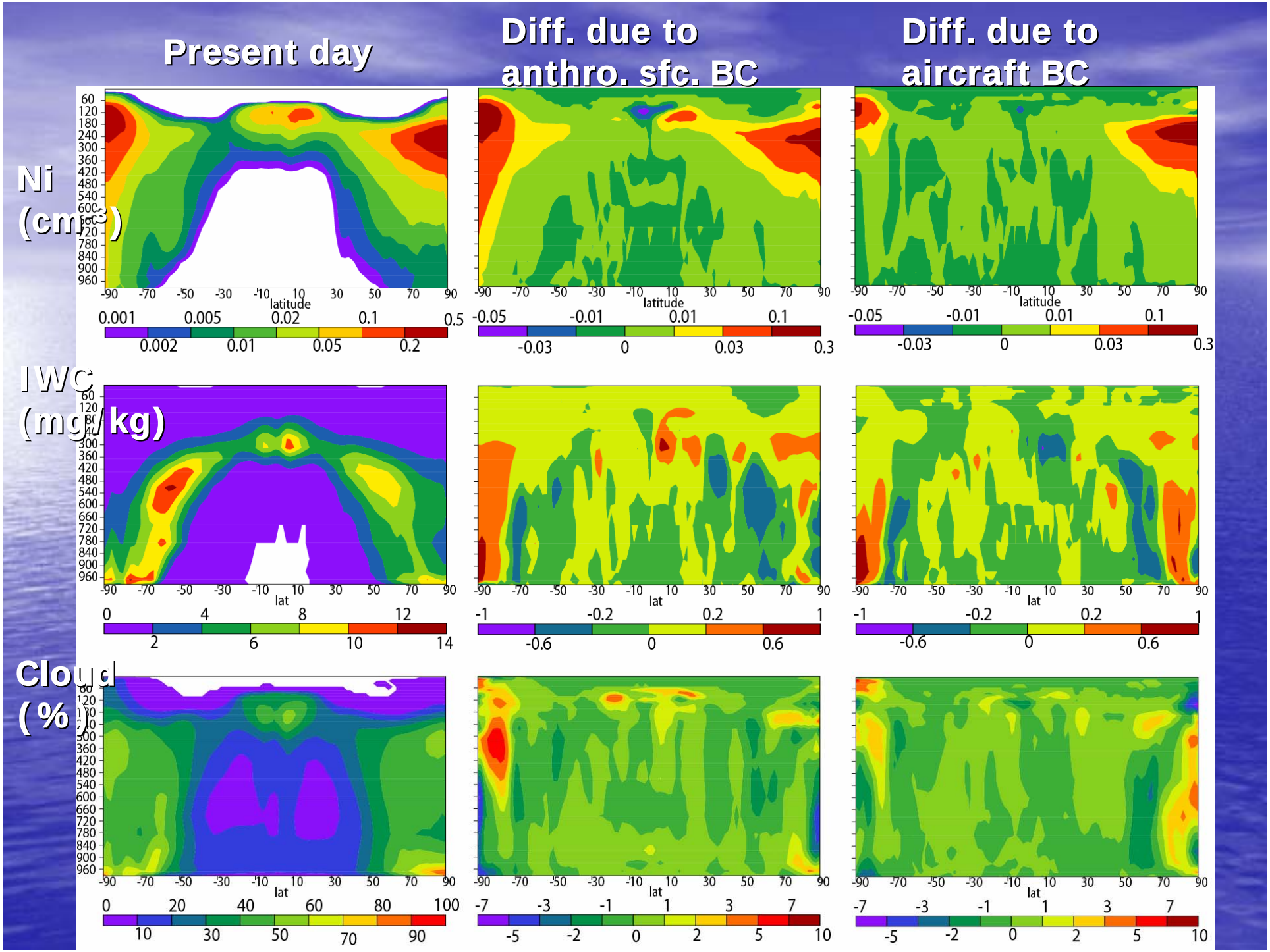


/m3

~1 cm^{-3}

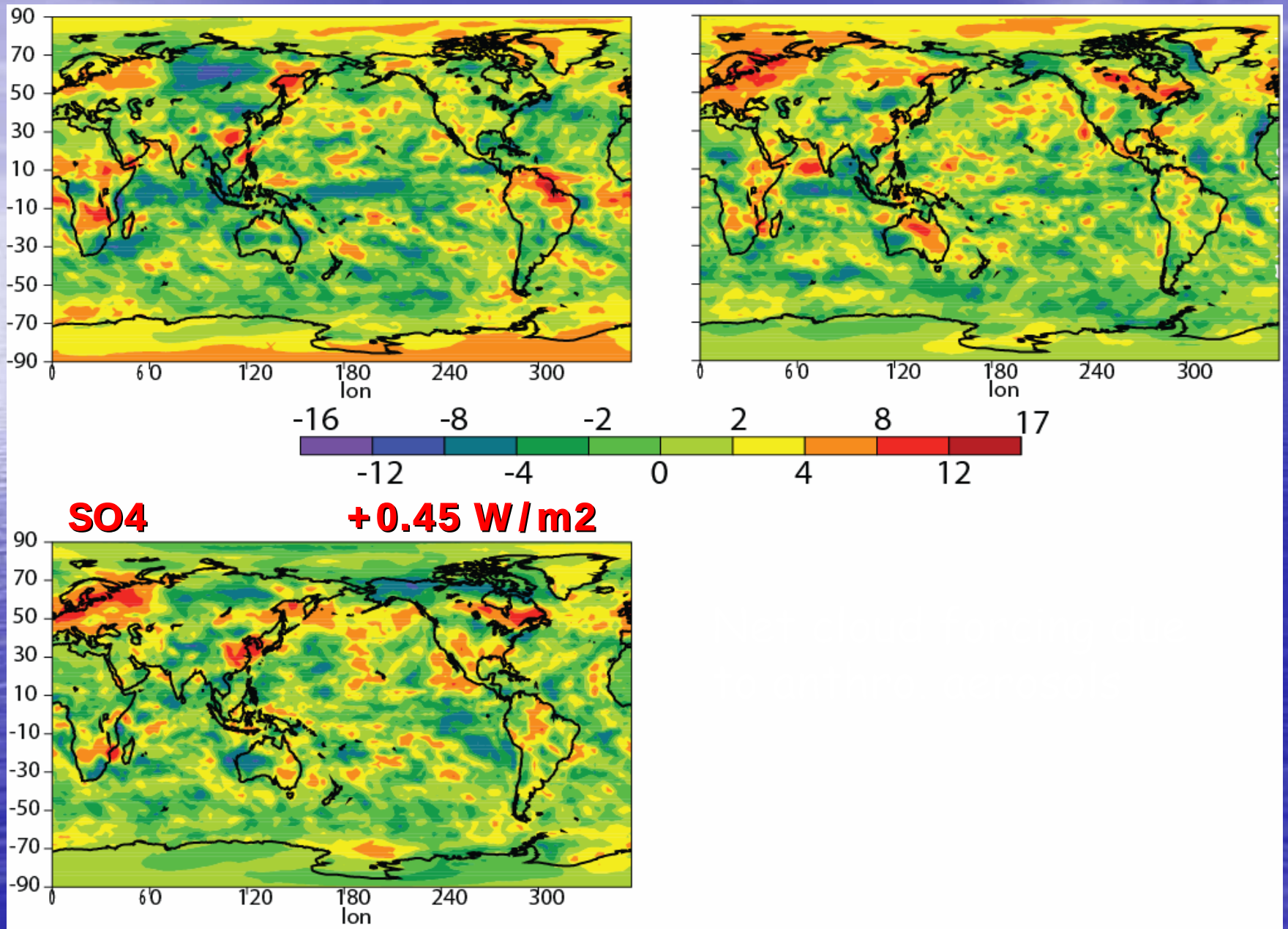
m^{-3}

Size distribution of soot from surface sources & from aircraft in the upper troposphere (Pusechel et al., 1992; Petzold & Schrolder, 1998)


Present day
Diff. due to anthro. sfc. BC
Diff. due to aircraft BC
Ni (cm^{-3})
IWC (mg/kg)
Cloud (%)
latitude
lat
0.001 0.005 0.02 0.1 0.5
0.002 0.01 0.05 0.2
-0.05 -0.01 0.01 0.1
-0.03 0 0.03 0.3
0 4 8 12
2 6 10 14
-1 -0.2 0.2 1
-0.6 0 0.6
0 20 40 60 80 100
10 30 50 70 90
-7 -3 -1 1 3 7
-5 -2 0 2 5 10

Surface soot +0.3 W/m2

Aircraft soot +0.58 W/m2



SO4 +0.45 W/m2

Summary

- NCAR CAM and LLNL/Umich IMPACT aerosol model are coupled using a component code structure, and the 2 executables are concurrently run in MPMD mode in a parallel environment. MPH is used to initialize the MPI and to map the processors to components.
- The coupled model simulated reasonable aerosol fields
- The predicted sulfate aerosol number has large impact on the calculated cloud properties.
- Effects of aircraft and surface emissions of BC and SO4 on ice clouds are being simulated