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Assessment of sulfate aerosols and its uncertainty due to clouds using global models

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(collaborating with Prof. Terry Nakajima et al.)

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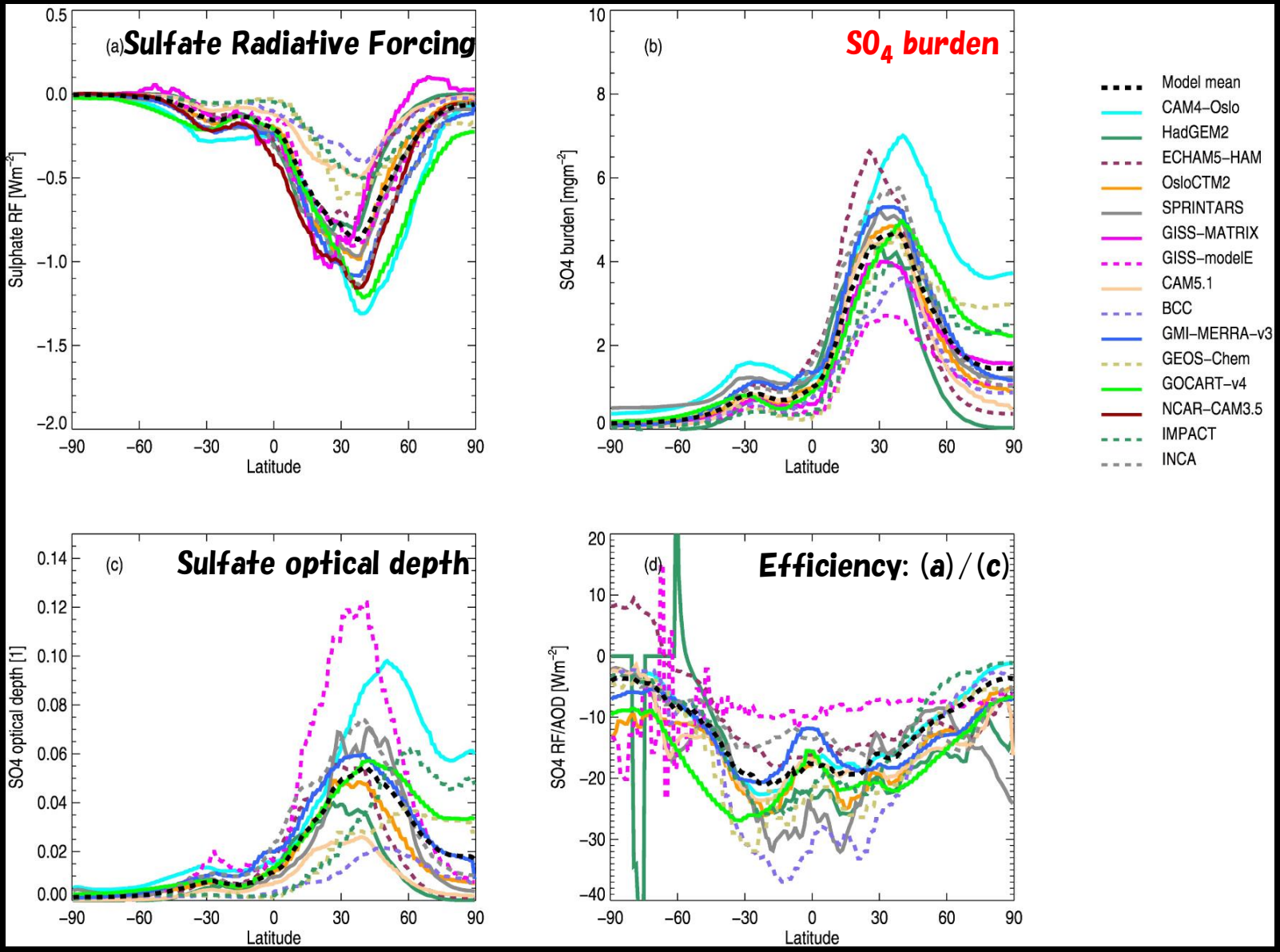
First of all…

Land use and cover changes mainly provide carbonaceous aerosols,
and its modeling is very important,
but sorry for talking about sulfate aerosol modeling

Model variability: Sulfate distributions in a global scale

Annual and Zonal Mean Values of sulfate under AeroCom project

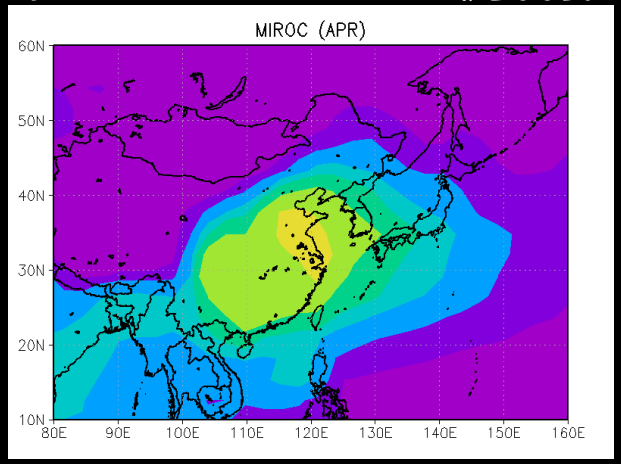


[Myhre et al., 2013, Atmos. Chem. Phys.]

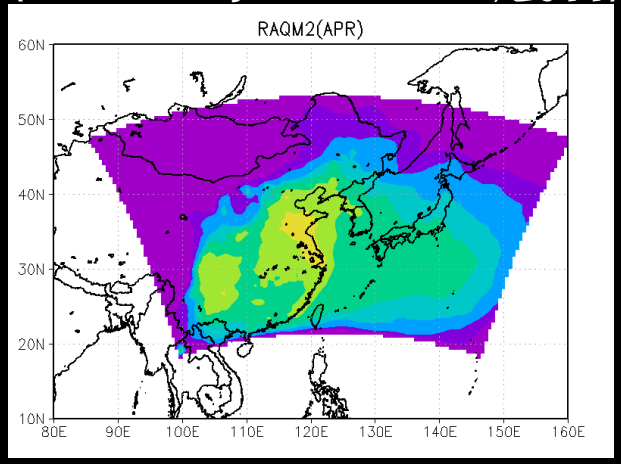
Model variability: Sulfate distributions in a regional scale

Surface sulfate in April 2006 over East Asia

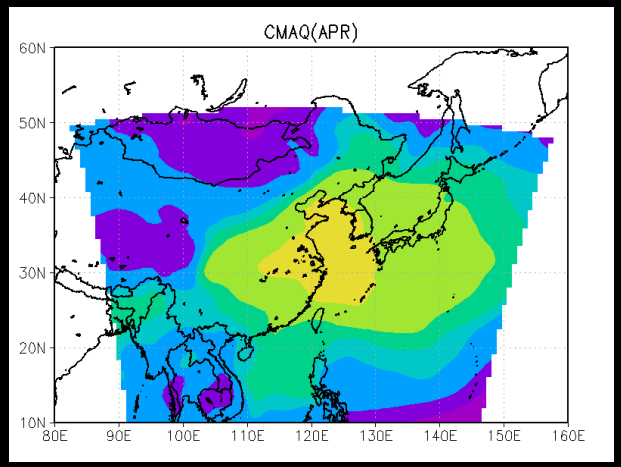
MIROC-SPRINTARS (based on Takemura et al., 2005)



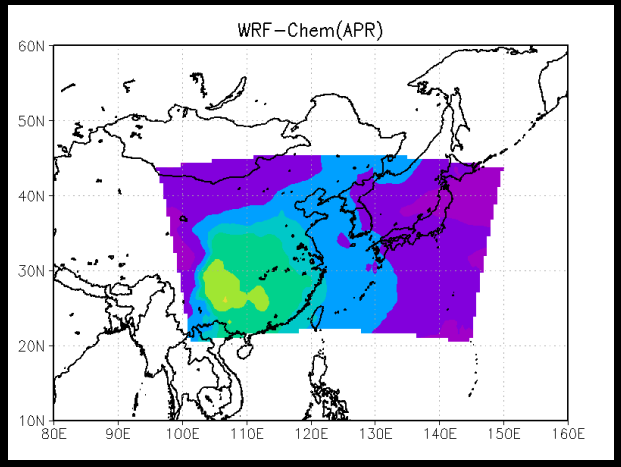
RAQM2 (based on Kajino and Kondo, 2011)

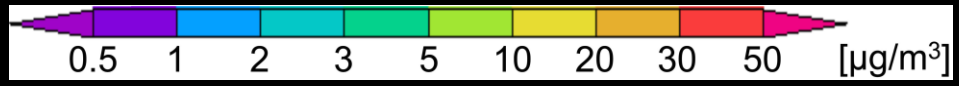


RAMS-CMAQ (Hara et al., 2011)



WRF-Chem (Matsui et al., 2011)





What is the model uncertainties?

Difference in the experimental conditions

- Resolution
  - Horizontal: 100-300 km (global) / 20-50 km (regional)
  - Vertical: 20-50 layers
- Emission inventory
  - EDGAR, REAS(Asia), INTEX-B(Asia), … but recent international projects use the common inventory.

Difference in the models

- Host model (dynamic core): At least 20 different modules
  - Basic variables (T, Q, U, V)
  - Horizontal/vertical transports
  - Radiative transfer model
  - Cloud/Precipitation

Focus on this difference

- Aerosol model: At least 20 different modules

Our approach to investigate the uncertainty

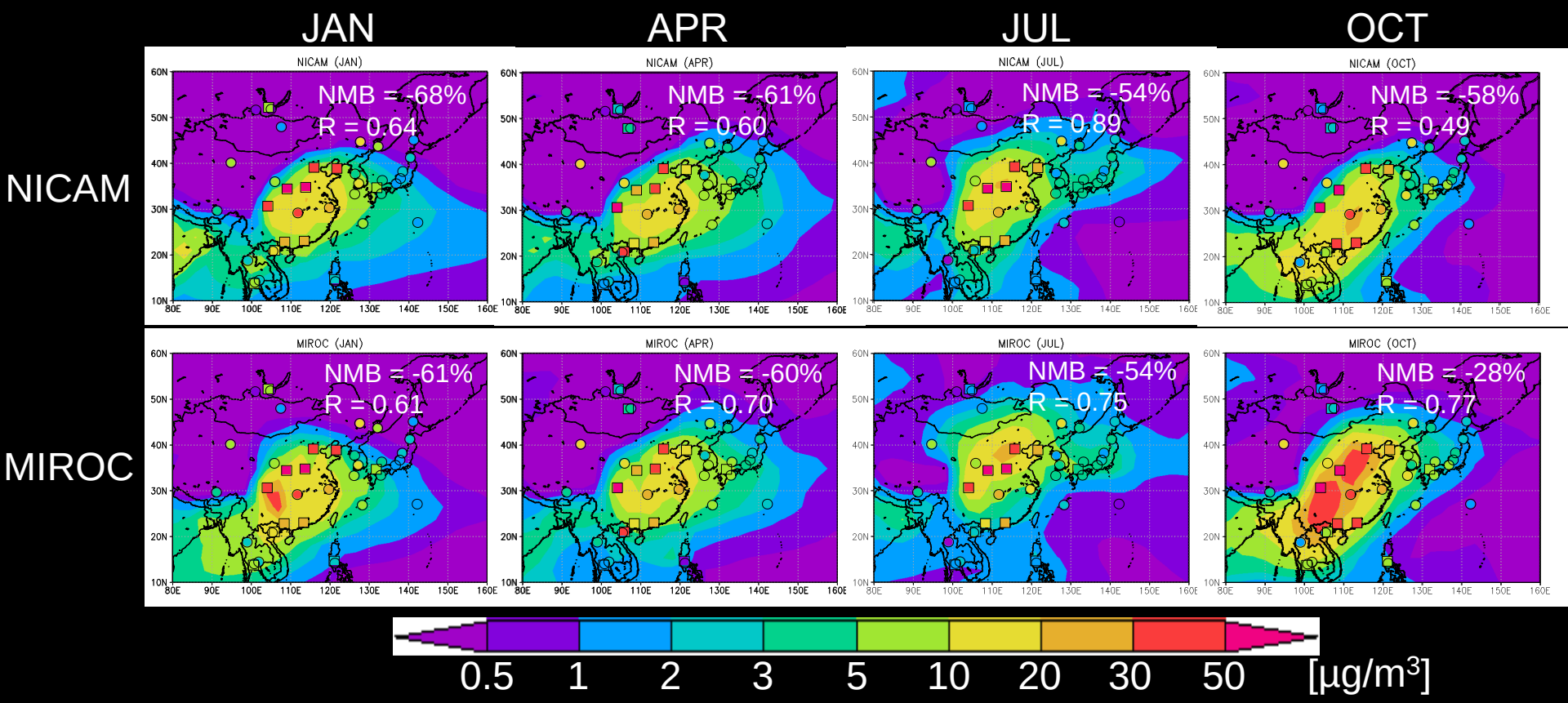
- Experimental designs:
  - Same (similar) resolution, emission inventory, & aerosol module, but different host model
    - MIROC and NICAM
      - MIROC is a typical general circulation model (GCM) using a spectral method
      - NICAM is also GCM, but can be cloud-resolving GCM using a grid point method
    - Almost-same module in physical processes
      - cloud/radiation/turbulence/land surface
    - Nudged by reanalysis (NCEP/FNL) every 6 hr, >2 km height
- Target:
  - Sulfate (representative secondary aerosols)
  - East Asia (especially China-Korea-Japan)
  - 4 month (January, April, July, October) in 2006

Experimental conditions in details

		New	Original
Host model	Dynamic core	NICAM (Tomita & Satoh, 2004; Satoh et al., 2008, 2014)	MIROC (Emori and Hasumi, 2004; Watanabe et al., 2010)
		Non-hydrostatic icosahedral atmospheric model	General Circulation Model (GCM)
	Transport	Improved van Leer (1977) (Miura, 2007; Niwa et al., 2011)	van Leer (1977), Lin & Rood (1996) for the poles
	Nudging	Only winds by NCEP-FNL above 2 km height every 6 hour	
	Cloud	Le Treut & Li (1991), Arakawa & Schubert (1974)	
	Auto-conversion	Berry (1967)	
	Boundary layer	Meller & Yamada (1974), Nakanishi & Niino (2004, 2006)	Meller & Yamada (1974)
Aerosol module	Module	SPRINTARS (Takemura et al., 2000; 2002; 2005; 2009)	
	Sulfur chemistry	Gas-phase: SO_2+OH ; Aqueous-phase : SO_2+{H_2O_2, O_3}	
	Oxidants	Offline-calculated {OH, H_2O_2, O_3} by CHASER (Sudo et al., 2002)	
	Sizes for sulfate	radius=69.5nm、 1-moment bulk	
Experimental designs	Inventory	INTEX-B (Zhang et al., 2009)	
	Horizontal res.	g-level 5 (220 km)	T42 (=2.8 deg)~300km
	Vertical res.	40 (10 layers within 2km)	56 (10 layers within 2km)

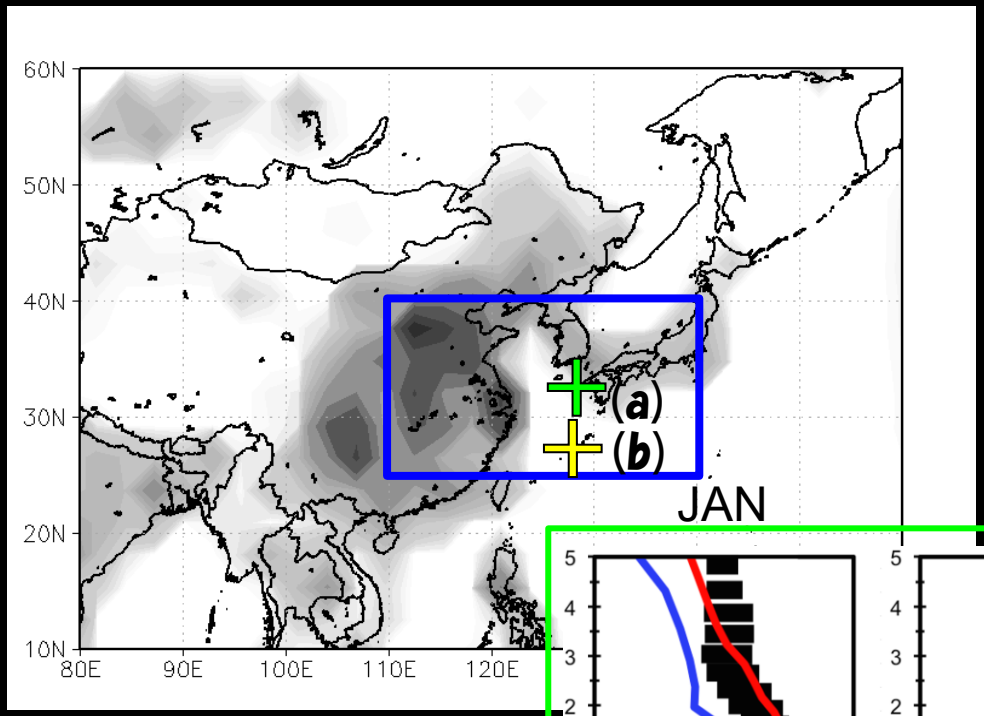
Results: Surface sulfate aerosols

Measurement data: Zhang et al. (2012) over China, EANET over East Asia, Dr. A. Takami at Cape Hedo and Drs. A. Takami & S. Hatakeyama at Fukue

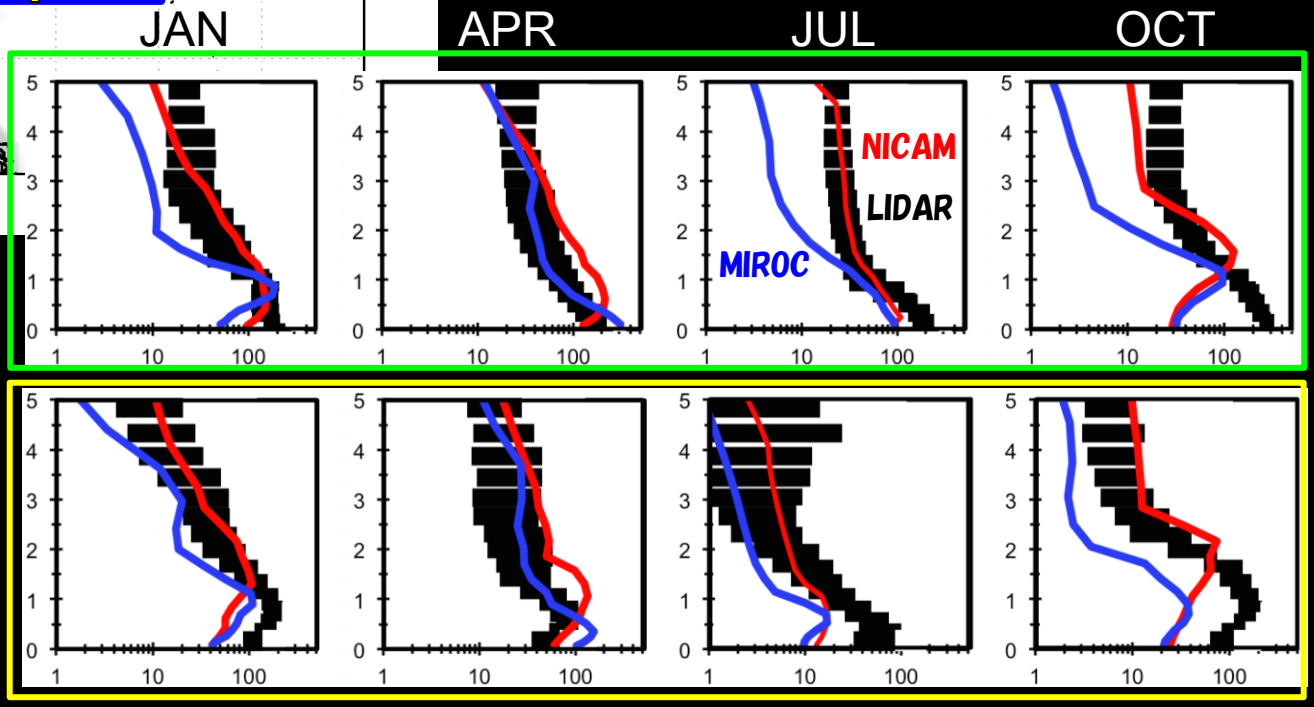


Results: Vertical distribution for extinction

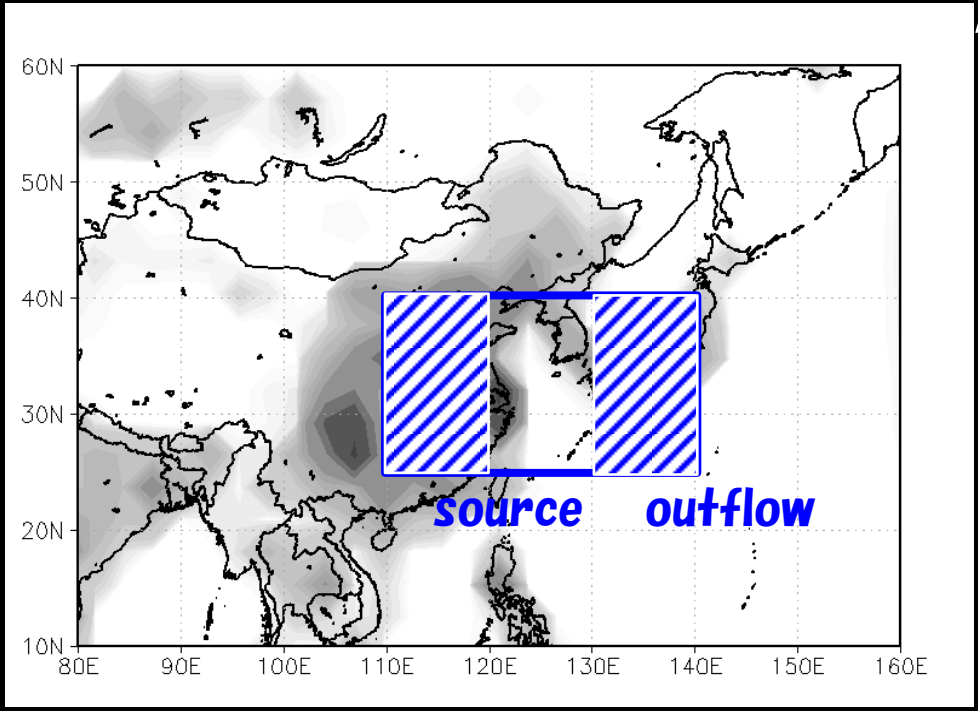
Lidar data: Drs. N. Sugimoto & A. Shimizu



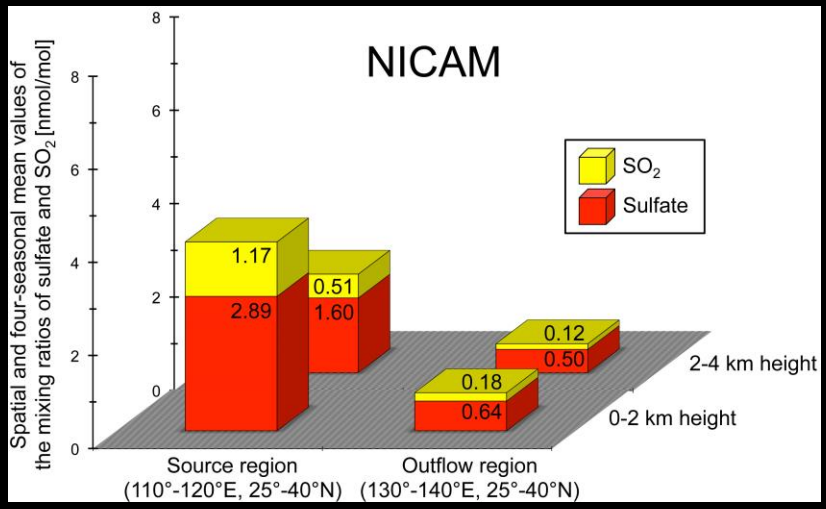
Extinction for spherical particles (Sulfate, carbon, and seasalt) ∝ Aerosol mass, optical properties as well as RH

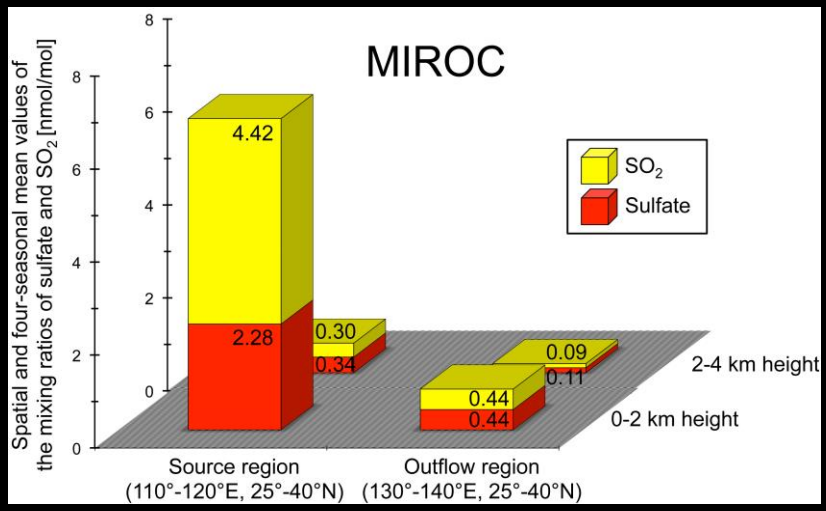


Discussion: Difference in sulfur between NICAM and MIROC



Annual mean values for the burdens

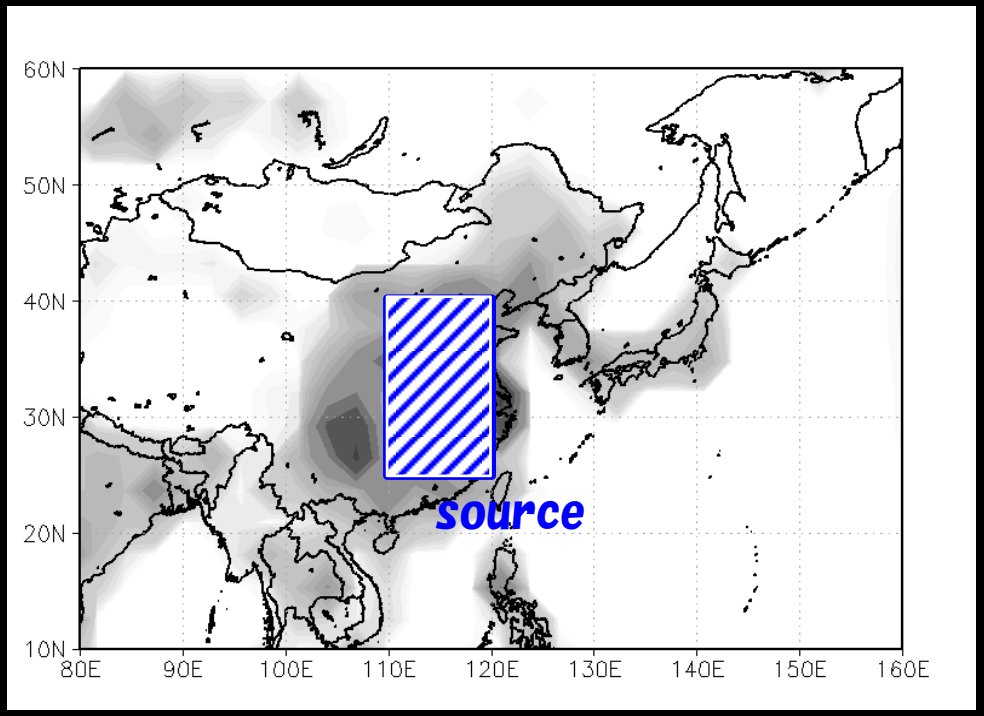




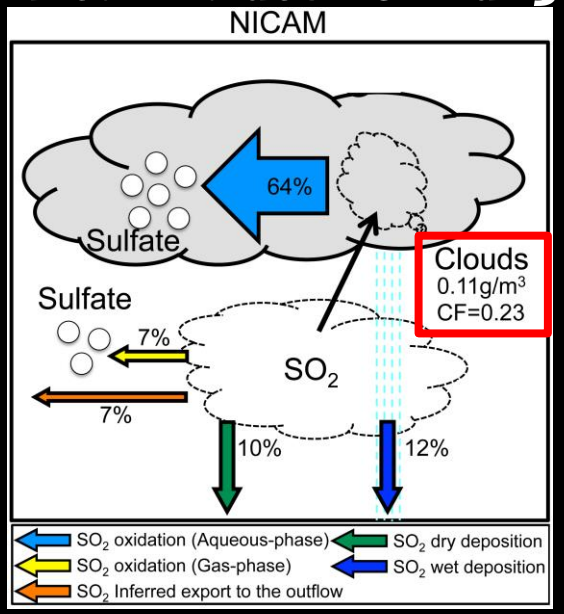
Points:

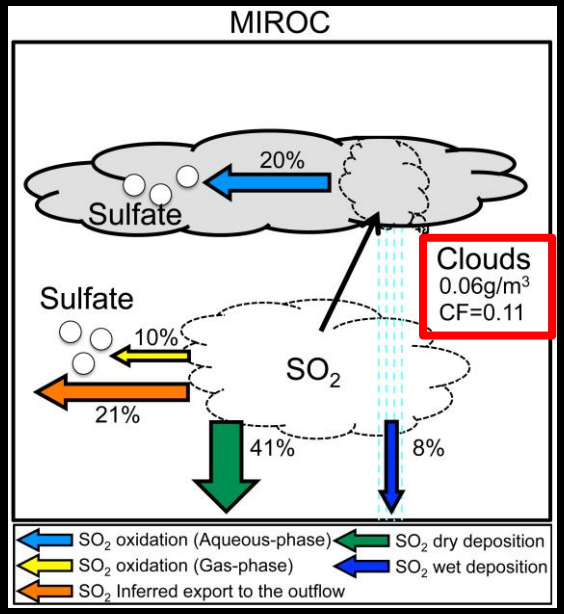
1) In NICAM, more SO_2 are converted into sulfate over the source regions.
2) NICAM-simulated sulfate are more distributed above 2 km heights

Discussion: Difference in sulfur between NICAM and MIROC



Annual mean values for budget flux



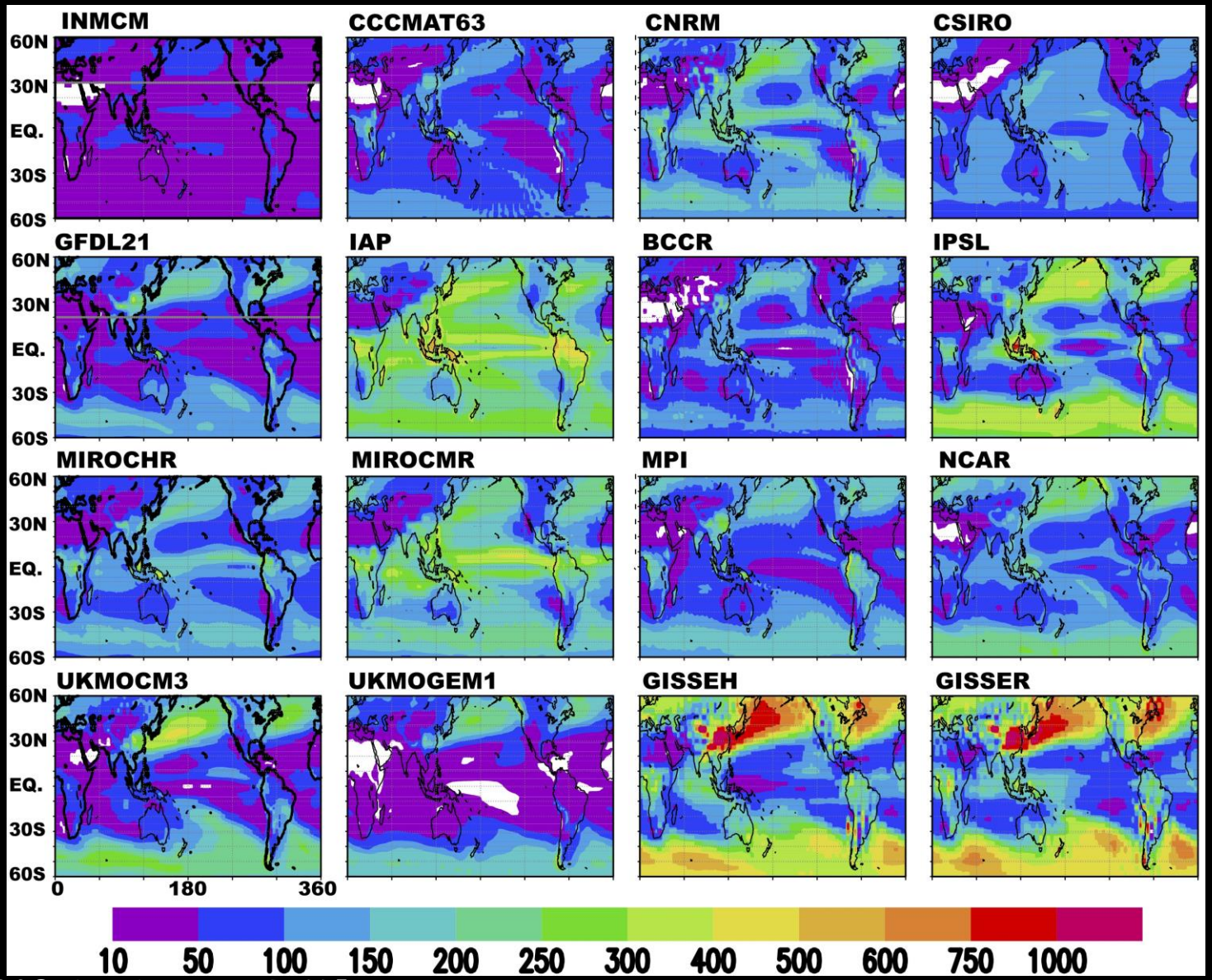


Points:

1) The difference in clouds strongly affects the difference in sulfate.
2) However, the difference in clouds may be inevitable, because models have own suitable tuning parameters in subgrid-scale cloud parameterization.

Large uncertainty in simulating clouds by GCM

Cloud Liquid Water Path [g/m²]

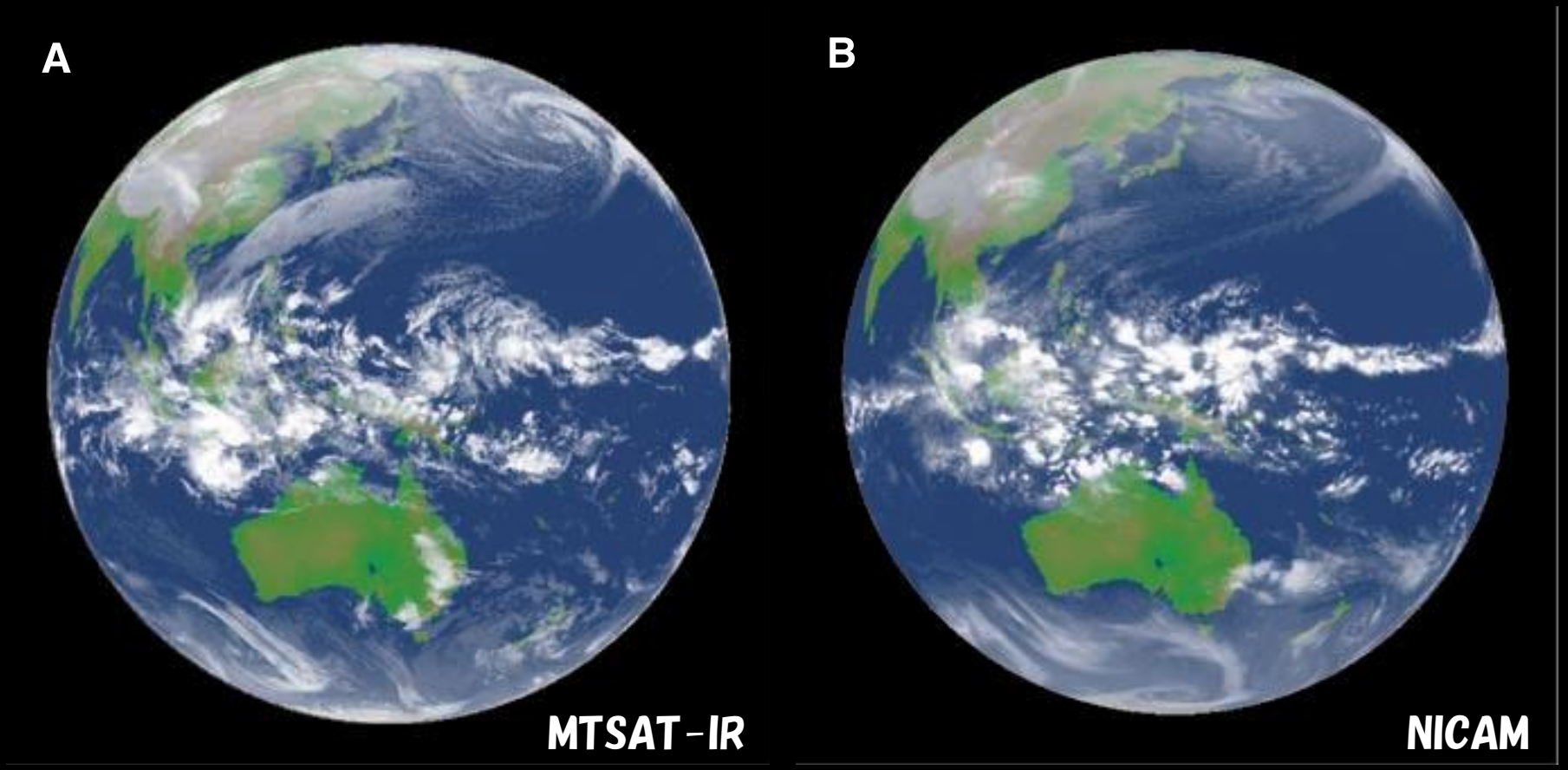


[Li et al., 2008, Geophys. Res. Lett.]

Toward a new generation model without cloud parameterization

Until now we showed results with O(100km) grid spacing,
but from now we show results with O(10km) grid spacing.

NICAM with 3.5km grid spacing : Cloud resolving model



dx=3.5km
[Miura et al., 2007, Science]

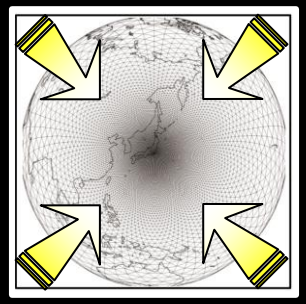
Aerosol modeling using NICAM-Chem with O(10km) grids

NICAM-Chem (Atmospheric aerosol-chemistry model coupled to NICAM)

Aerosol-Chemistry module

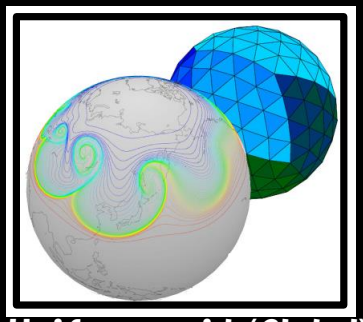
+

Nonhydrostatic ICosahedral Atmospheric Model (NICAM)



Scale-up

Regionalize



Stretched grid (Regional)

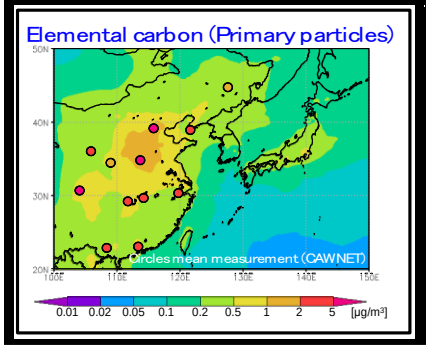
Uniform grid (Global)

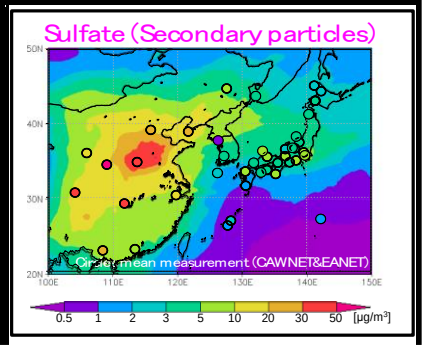
Seamlessly covering global-to-regional areas

Regional calculation

Global calculation

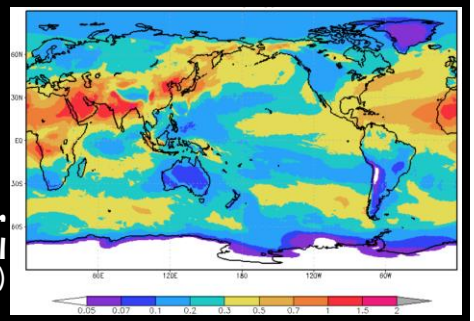
Validation (East Asia) by *Goto et al.* (2015)





Global distribution of the air pollution with high spatial resolution (up to 3.5km) using supercomputer K

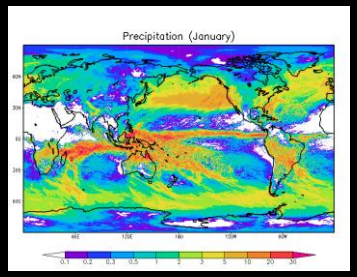
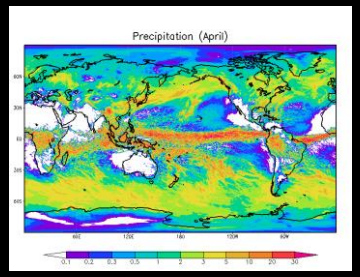
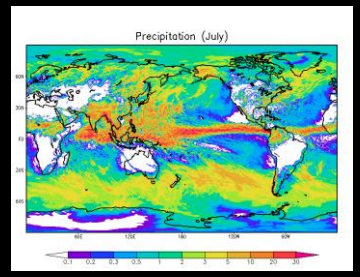
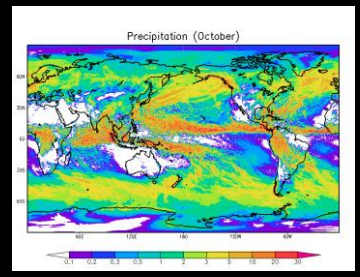
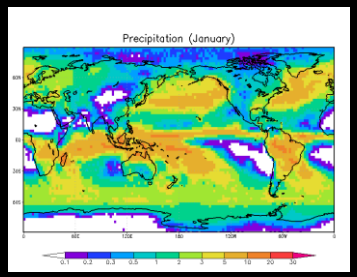
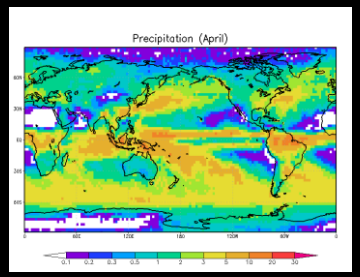
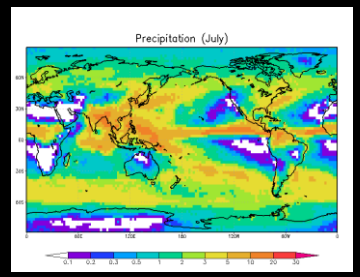
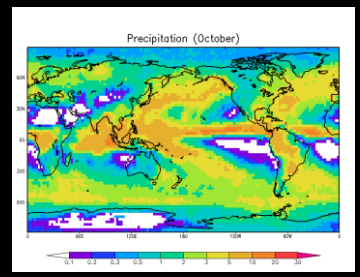
Aerosol Optical Depth (dx=14Km)



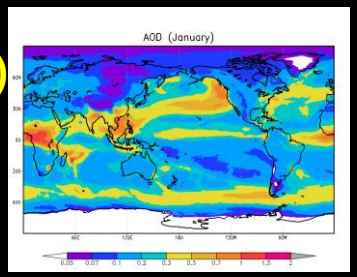
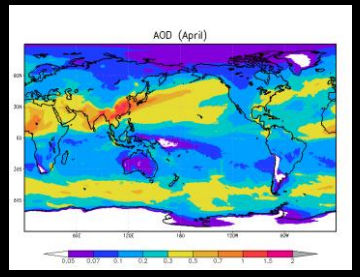
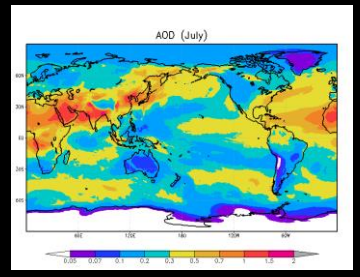
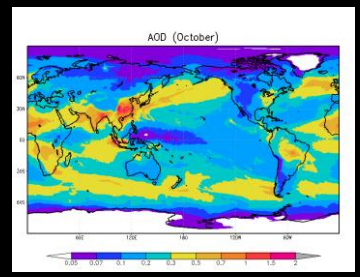
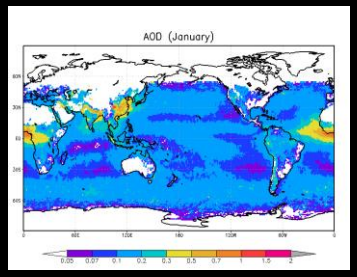
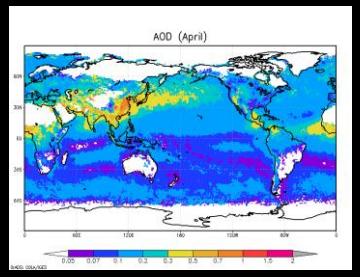
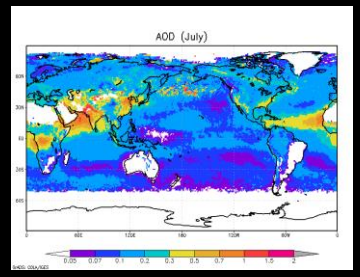
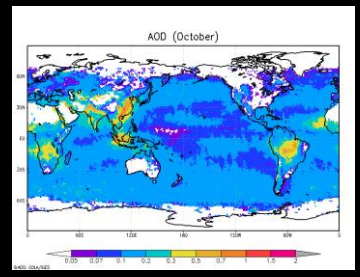
- Using the stretched grid system on NICAM-Chem with 10 km grids, we simulated aerosol and ozone distributions over East Asia and compare them with observation.
- Now, we are simulating NICAM-Chem as a global cloud-resolving model with <10 km grids.

Preliminary results by Global-NICAM-Chem with O(10km) grids

Precipitation [mm/day]

	JAN	APR	JUL	OCT
NICAM -Chem				
GPCP				

AOD (All species)

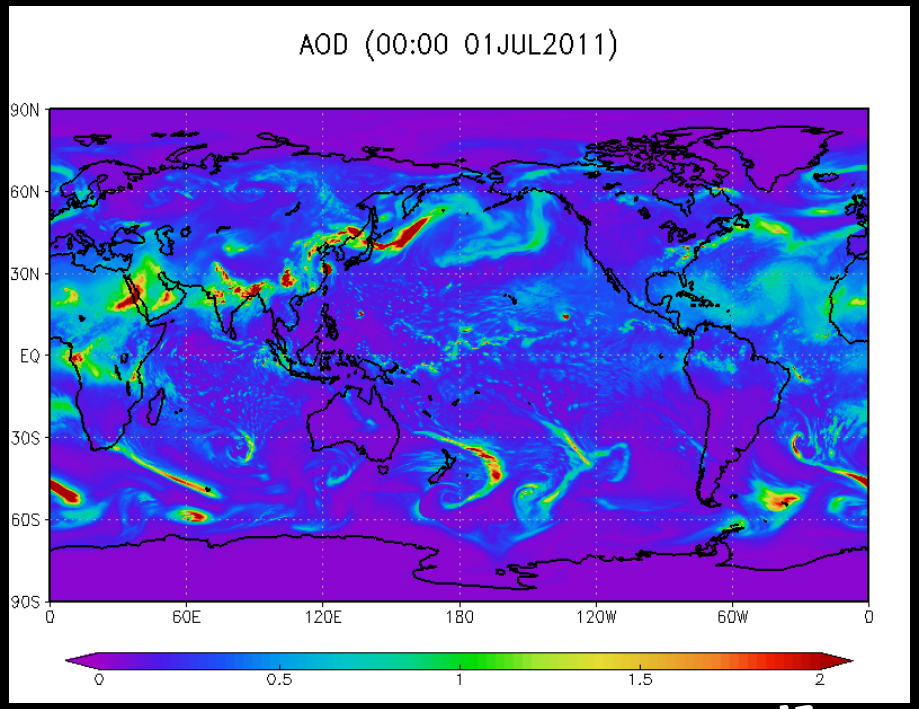
NICAM -Chem				
MODIS				

Summary

1. An inter-comparison study using common aerosol module is conducted: Same model, but different dynamic core: NICAM vs. MIROC (←Mainly clouds and possibly transport)

2. A variability in clouds among GCMs can strongly cause important differences in the sulfur distributions.

3. Toward a new generation model: Global simulation with high horizontal resolution with O(10km) grid spacing (e.g., it can investigate the impacts of biomass burning on regional and global air pollution and climate with high resolution.)



References:

Goto, D., et al. (2015), An evaluation of simulated particulate sulfate over East Asia through global model intercomparisons, J. Geophys. Res. Atmos., 120, doi: 10.1002/2014JD021693

Goto, D., et al. (2015), Application of a global nonhydrostatic model with a stretched-grid system to regional aerosol simulations around Japan, Geosci. Model Dev., 8, 235-259, doi: 10.5194/gmd-8-235-2015.

Thank you for your attention!