Study of Aerosol First Indirect Radiative Forcing with GEOS-Chem

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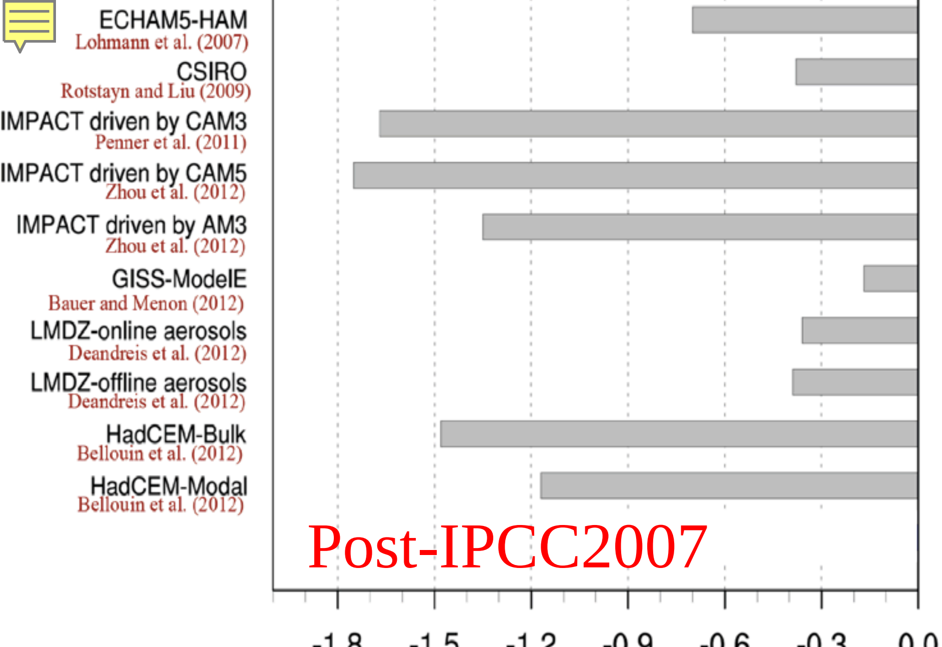
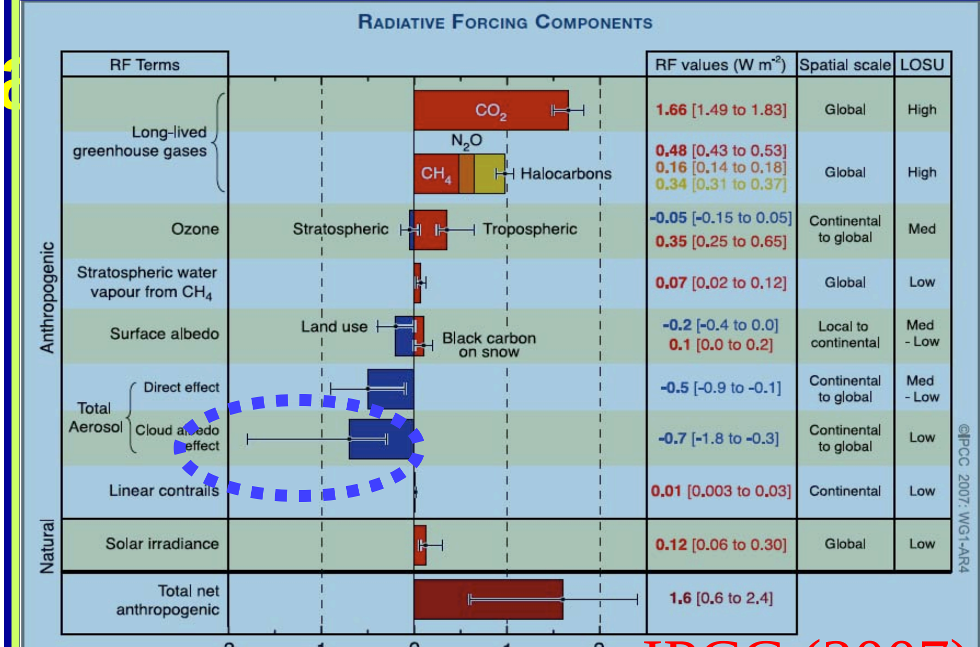
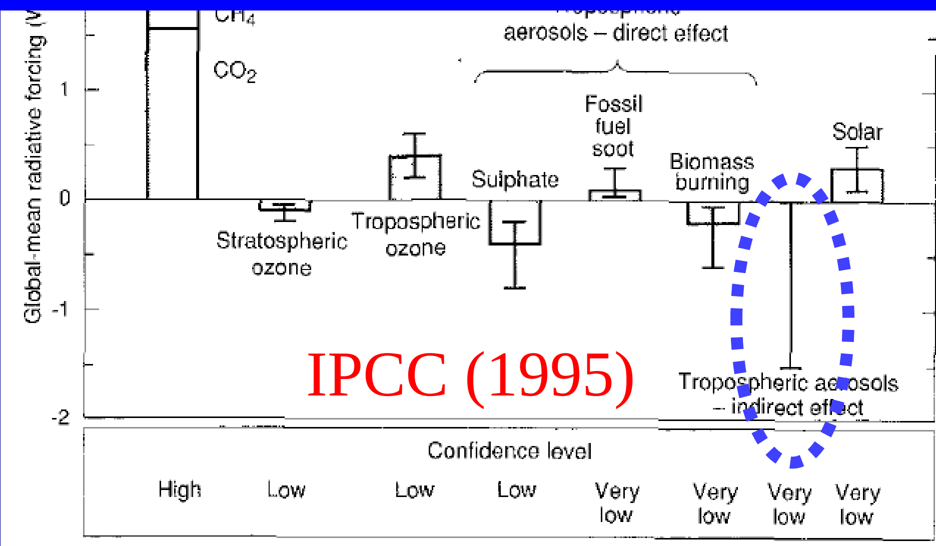
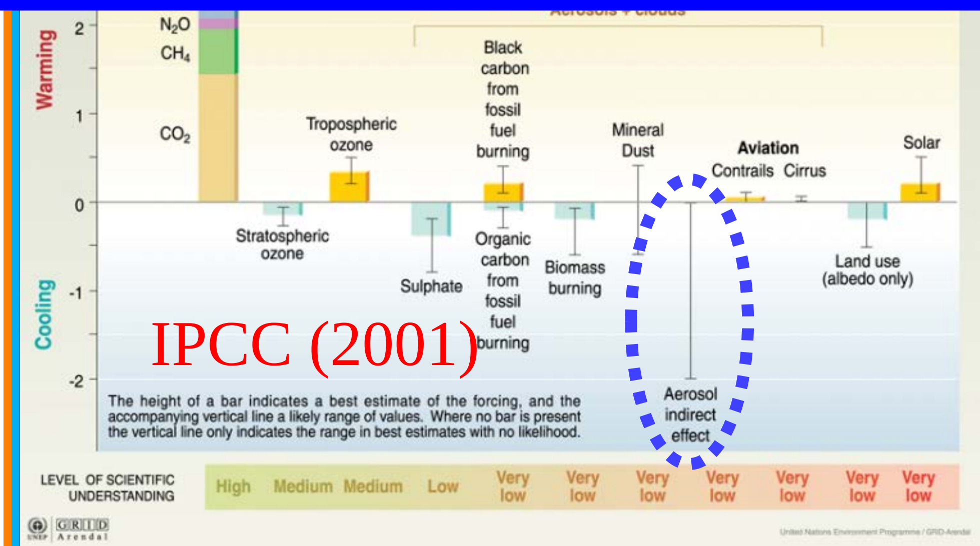




Can GEOS-Chem be used to study aerosol first indirect RF and help to reduce the uncertainty?





First Aerosol Indirect Radiative Forcing (IRF)

IPCC has defined the first indirect radiative forcing as:

Δ TOA solar fluxes $\leftarrow$ Δ cloud albedo $\leftarrow$ Δ aerosol concentration $\leftarrow$ anthropogenic emissions, with fixed meteorology (cloud fraction and liquid water content).

GEOS-Chem, as a CTM driven by assimilated meteorology, is perfectly suitable for the first IRF calculation.

Studies of aerosol first IRF (in W m^{-2}) published after IPCC (2007)

Study	Model type [a]	Chemistry	Aerosols [b]		First IRF	
			size	Species	approach	Value
Lohmann et al. (20[illegible]	ECHAM5-HAM	Sulfur cycle , with off-line monthly mean oxidants	Double-moment modal	SO_4,OC,BC, SS,D	Online	-0.7
Rotstayn[illegible] (20[illegible]	[illegible]	Sulfur cycle, with off-line monthly mean oxidants	bulk	SO_4,OC,BC, SS,D	Online	-0.38
Wang an[illegible] (2009); Penner et al. (2011)	[illegible] by CAM3 met	Sulfur cycle, with off-line monthly mean oxidants.	modal (two modes for sulfate)	SO_4,OC,BC, SS,D	Offline	-1.65 and -1.69
Zhou[illegible]	[illegible]	Sulfur cycle, with off-line monthly mean oxidants	modal (3 modes for sulfate)	SO_4,OC,BC, SS,D	Offline	-1.74 to -1.77
						-1.26 to -1.44
Bauer and Menon (2012[illegible]	GISS-modelE	Sulfur cycle, with off-line oxidants and nitric acid concentrations.	modal (2 moment)	SO_4,OC,BC, SS, D, NIT, NH4	Online	-0.17
Deandreis (2012[illegible]	[illegible]	Sulfur cycle , oxidants from an online chemistry model	bulk	SO_4	On-line	-0.36
					Offline	-0.39
Bellouin (2012[illegible]	[illegible]	Sulfur cycle, oxidants from an online chemistry model	bulk	SO_4, NH4, OC,BC,SS, SOA	Online	-1.48
			modal			-1.17

Simplified chemistry

Simplified Microphysics

None consider all major aerosols

Advanced features of GEOS-Chem/APM

- ✓ Online full (SOx-HOx-NOx-VOC-ozone) chemistry
- ✓ Full size-resolved (sectional) particle microphysics
- ✓ Relatively more accurate assimilated meteorology
- ✓ Online radiative transfer (RRTMG) calculation
- ✓ Consideration of important aerosol components (nitrate, ammonium, and SOA) that are not included in most of previous studies

Computing cost (for 1 yr simulation on 24-core workstation: 2^ox2.5^o, 47 layers)

Original model, 59 tracers, ~ **5** day

With APM, 59+94 = 153 tracers

no radiative forcing calculation: ~ **11** days

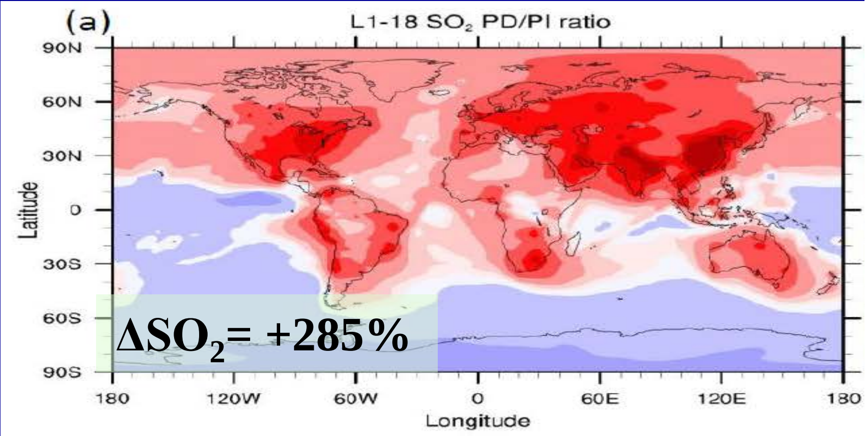
with radiative forcing calculation: ~ **13.5** days

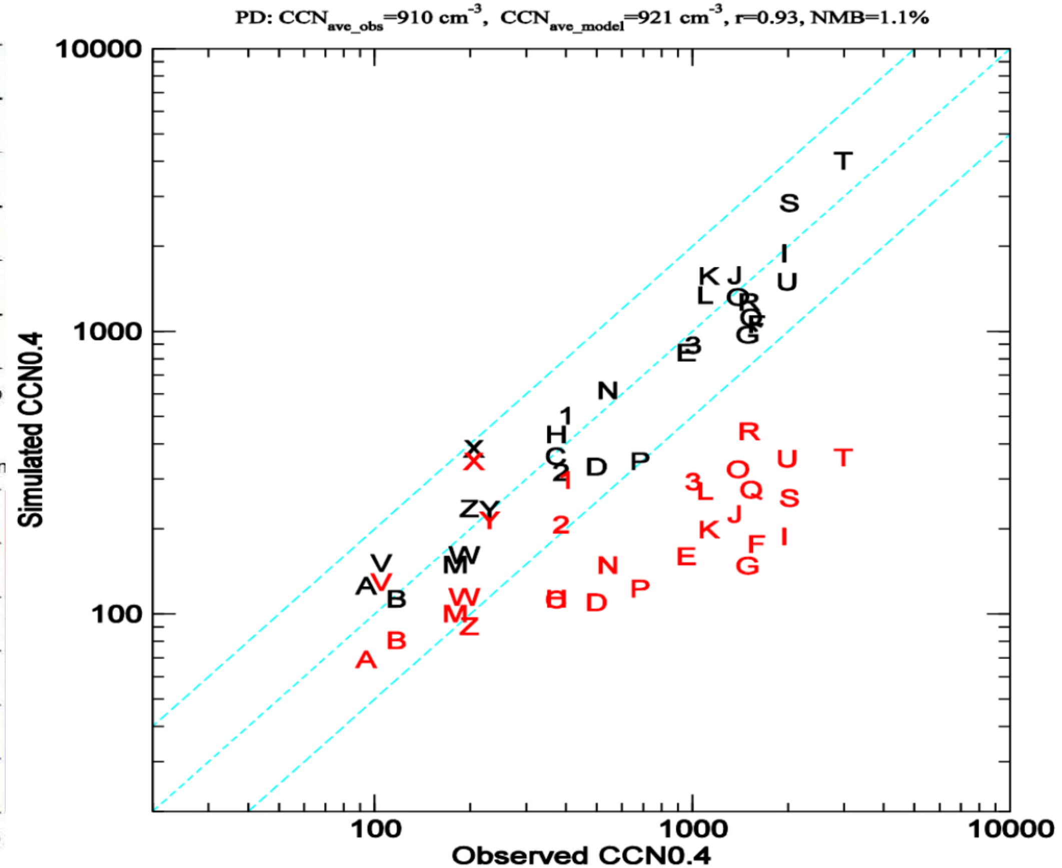
Study First Aerosol Indirect Radiative Forcing (IRF) with GEOS-Chem/APM

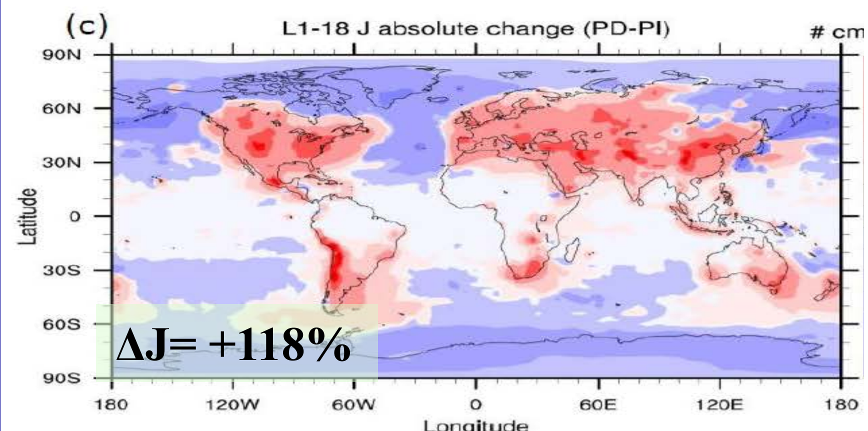
We ran two simulations driven by the same assimilated meteorology fields (2006): one with present day (PD) emissions and the other with pre-industrial (PI) emissions.

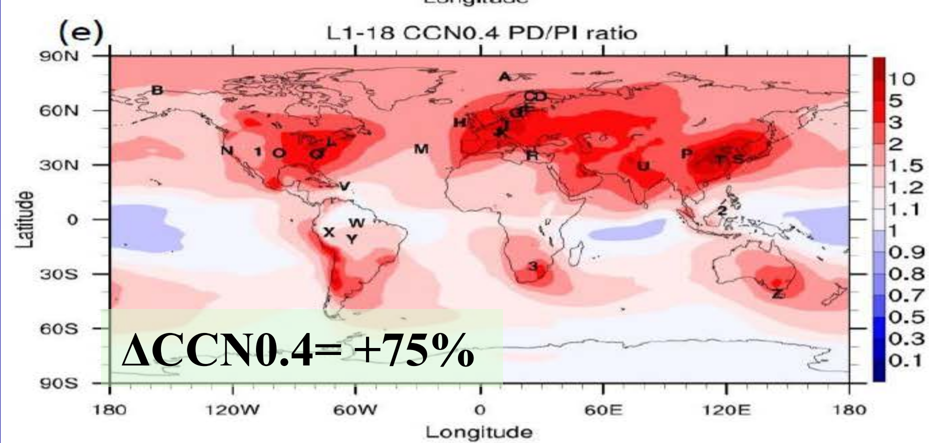
From PD and PI differences, we can study the impacts of anthropogenic emissions on aerosol properties and first IRF.

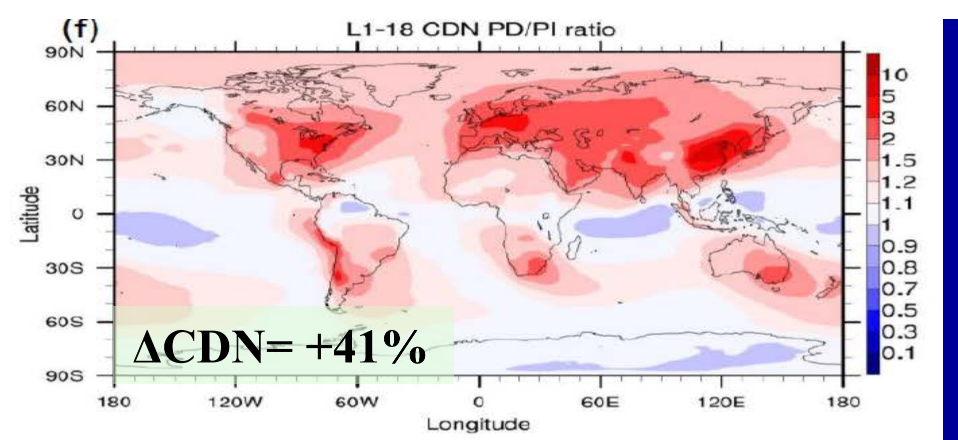
Impacts of anthropogenic emissions PD - PI

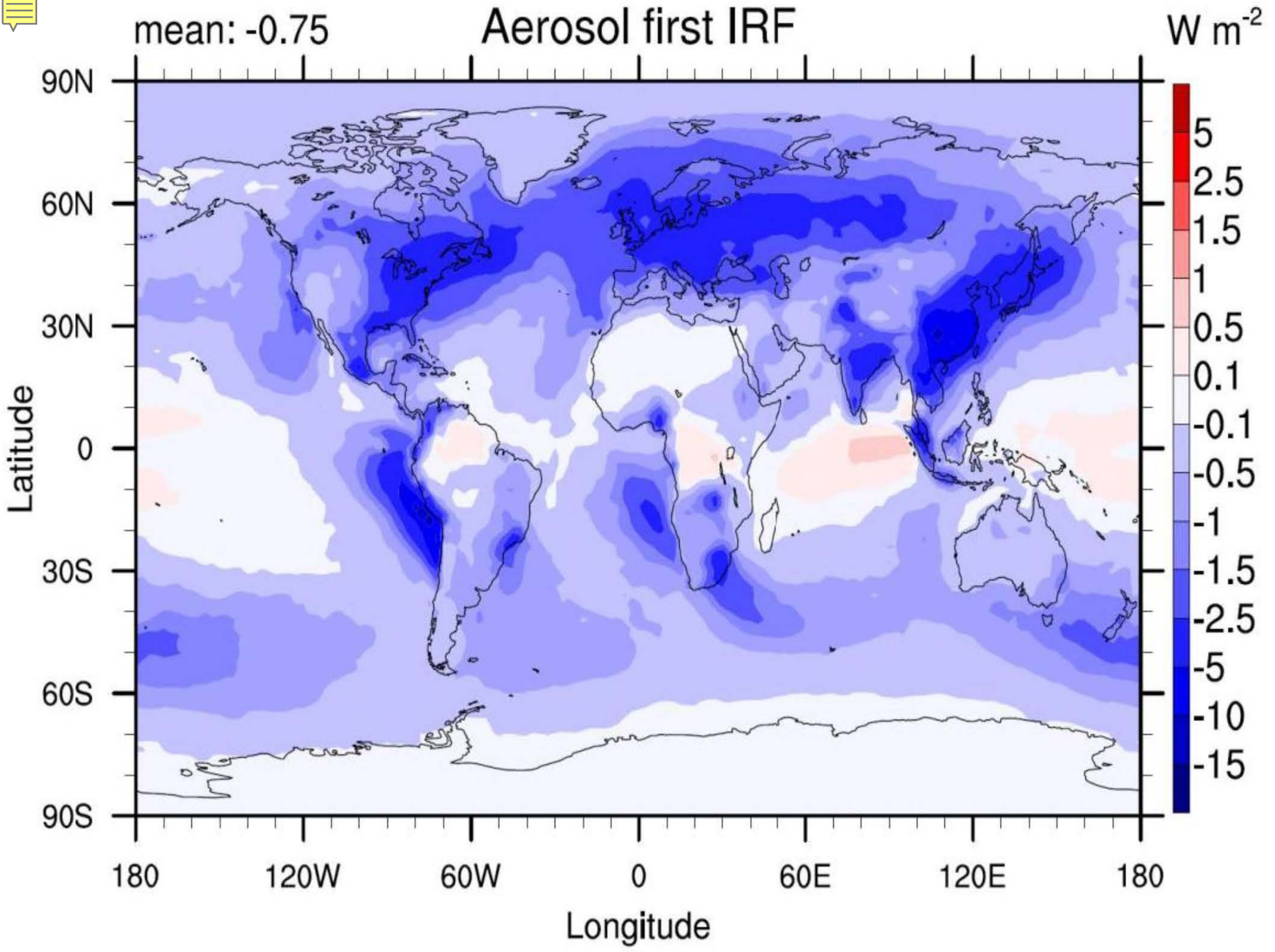












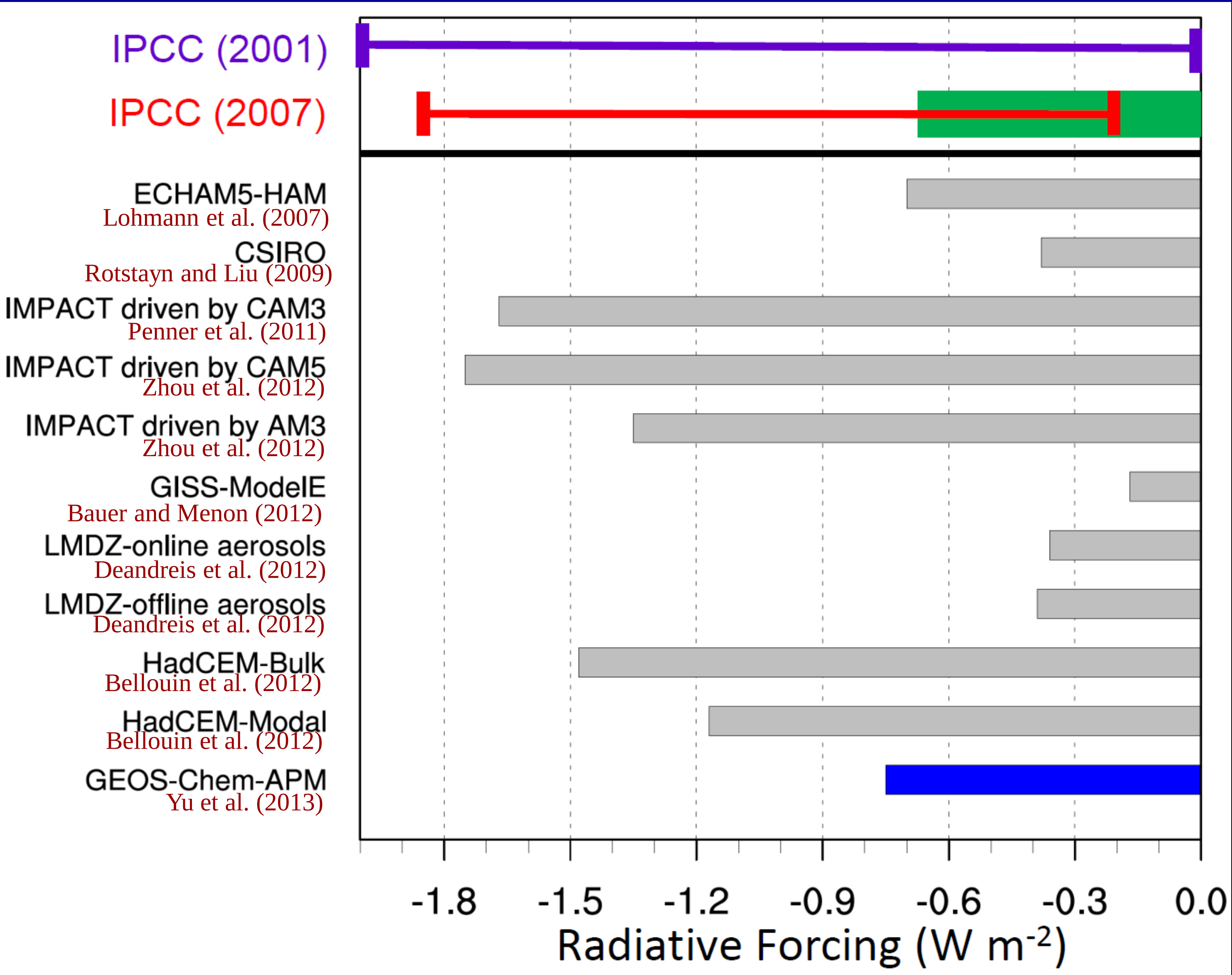
mean: -0.75
Aerosol first IRF
W m-2
90N
60N
30N
0
30S
60S
90S
Latitude
180
120W
60W
0
60E
120E
180
Longitude
5
2.5
1.5
1
0.5
0.1
-0.1
-0.5
-1
-1.5
-2.5
-5
-10
-15

First aerosol indirect radiative forcing

Post-

IPCC2007

studies



Summary

First aerosol indirect forcing is a major source of uncertainty in predicting climate change. GEOS-Chem/APM, containing a number of advanced features, has been adapted to study the first indirect forcing.

Based on GEOS-Chem/APM, anthropogenic emissions increase global mean CCN in the lower troposphere by ~60-80% and cloud droplet concentration by ~40%. The global mean first indirect forcing is –0.75 W m^{-2}.

Large diversity of first indirect forcing values still exists among the post-IPCC2007 studies. GEOS-Chem/APM can be a viable tool for studying the possible reasons of the diversity.

Thank you !

Aerosol optical properties and radiative forcing

based on GEOS-Chem-APM (Yu et al., 2012, 2013; Ma et al., 2012)

Optical properties

Core-shell model (Ackerman and Toon, 1981)

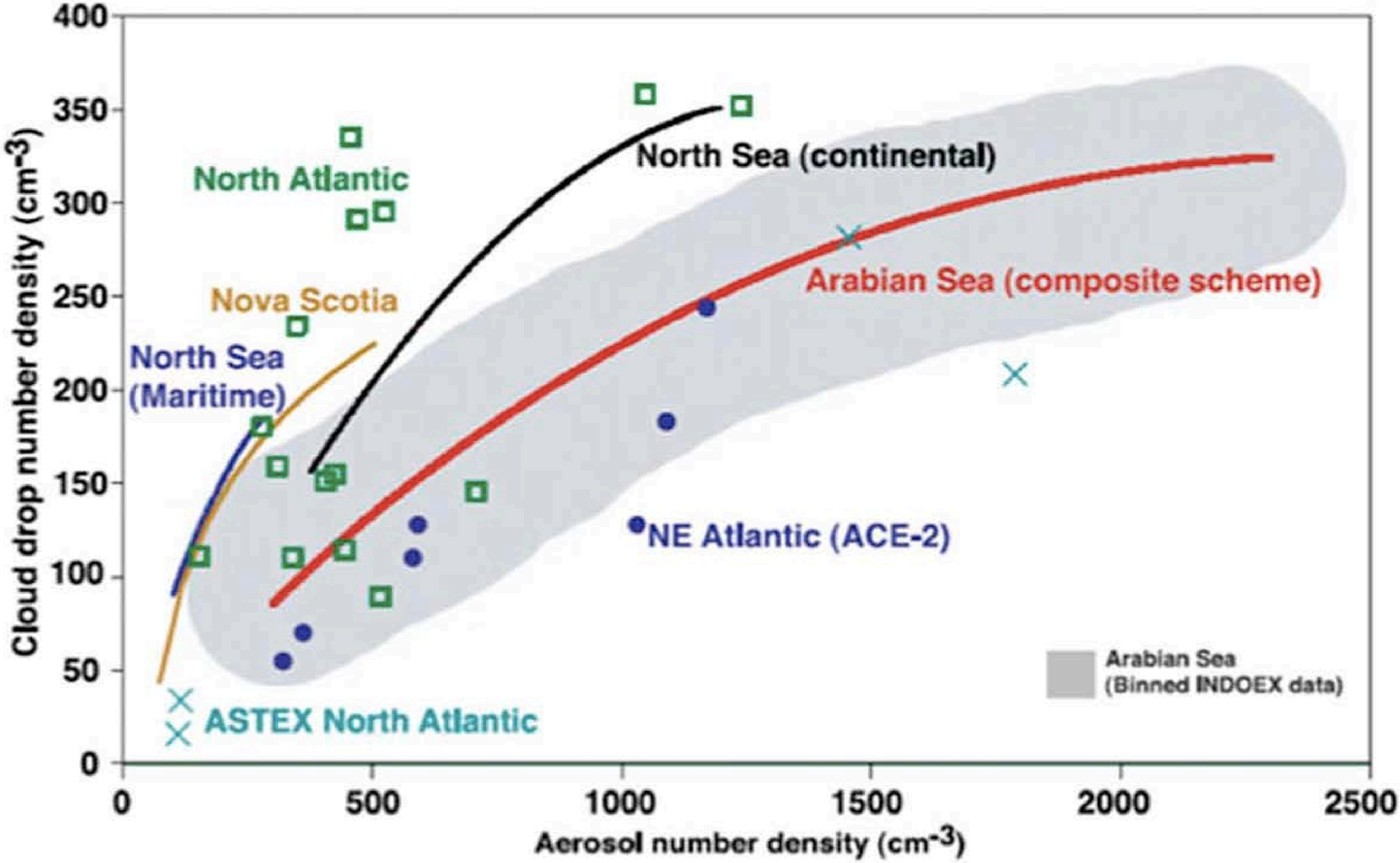
Radiative transfer

AER column RRTMG model (Clough et al., 2005)

Aerosol-cloud interaction

Cloud droplet formation (Abdul-Razzak and Ghan, 2002)

Effects of aerosol on cloud droplet concentration



Ramanathan et al., Science, 2001.

Advanced Particle Microphysics (APM) model

Turco et al., 1979; Jacobson et al., 1994; Yu and Turco, 1998; Yu, 1998; Yu and Luo, 2009; Yu, 2010; Luo and Yu, 2011; Ma et al., 2012; Yu et al., 2012, 2013

Secondary particles (SP) : 40 bins
(composed of SO4, NO3, NH4, SOA)

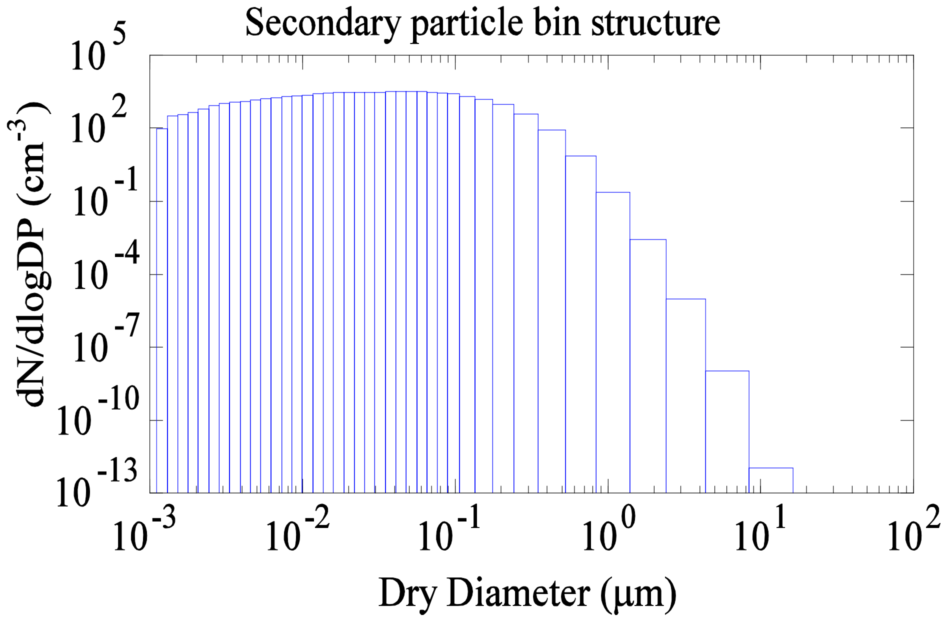
Sea salt particles: 20 bins

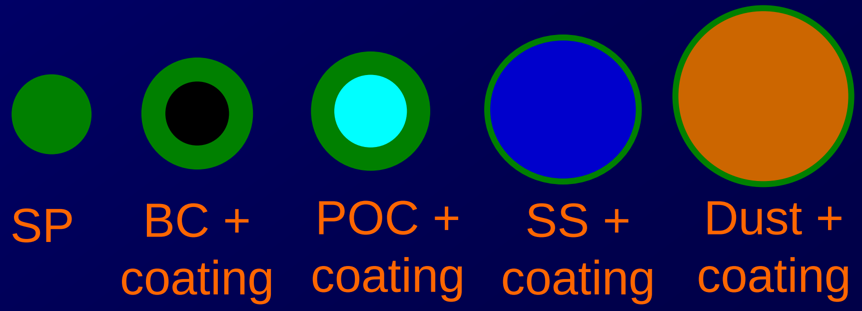
Dust: 15 bins

BC: two log-normal modes (one for fossil fuel, the other for biomass burning)

Primary OC: two log-normal modes

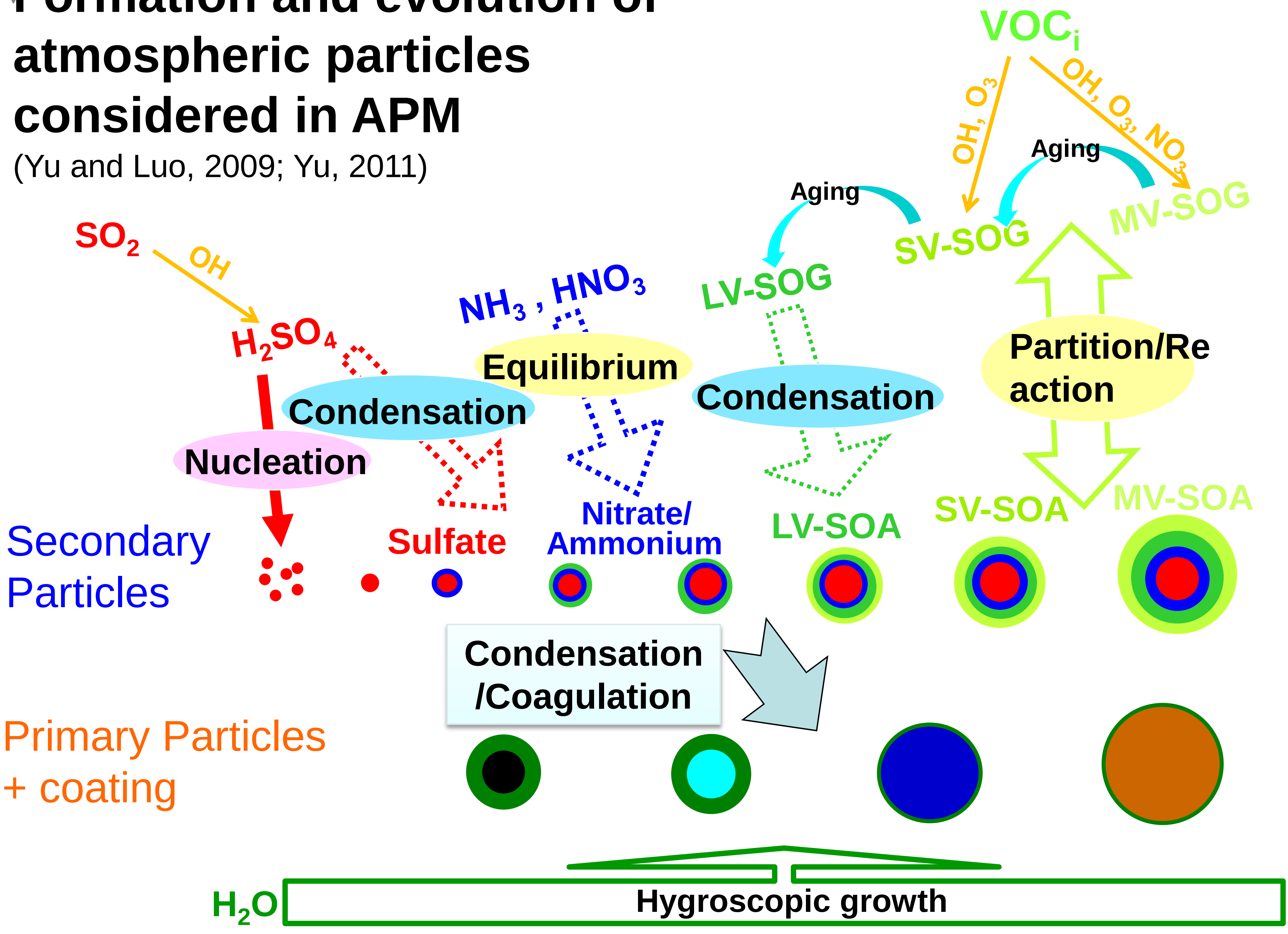
Coating of primary particles by secondary species tracked.

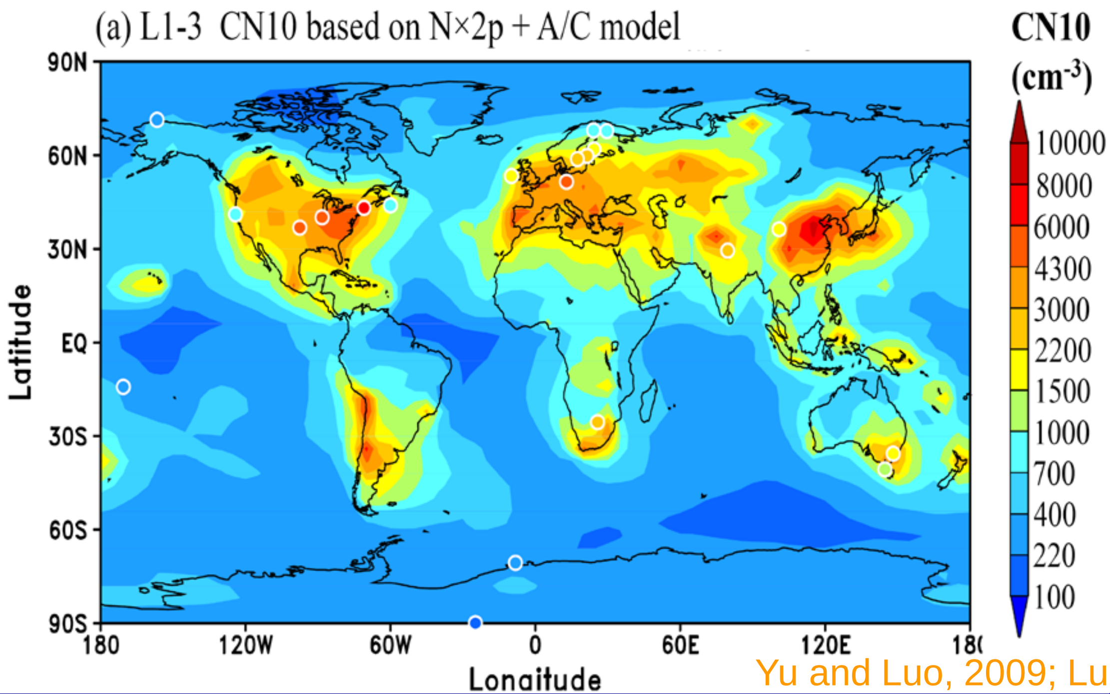


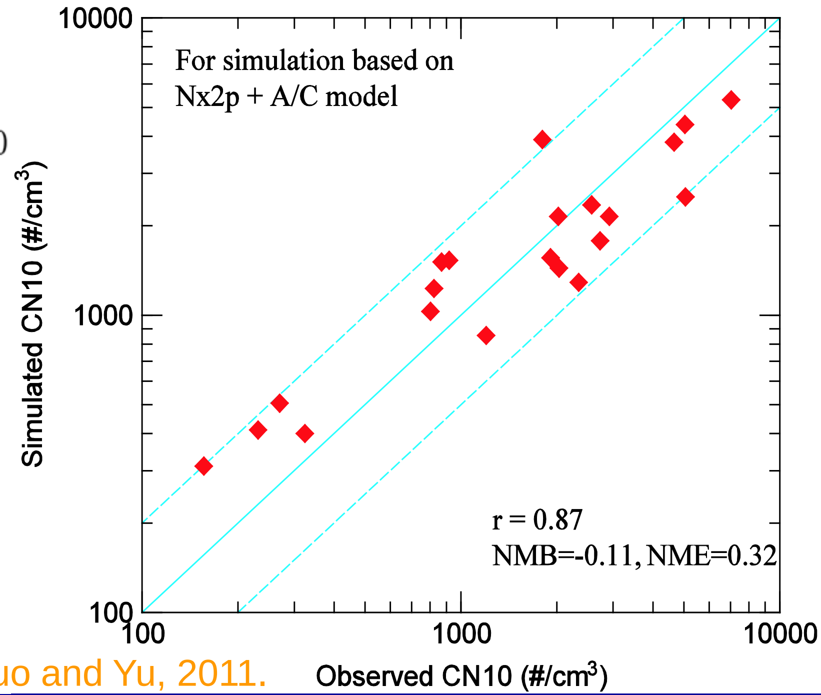


Formation and evolution of atmospheric particles considered in APM

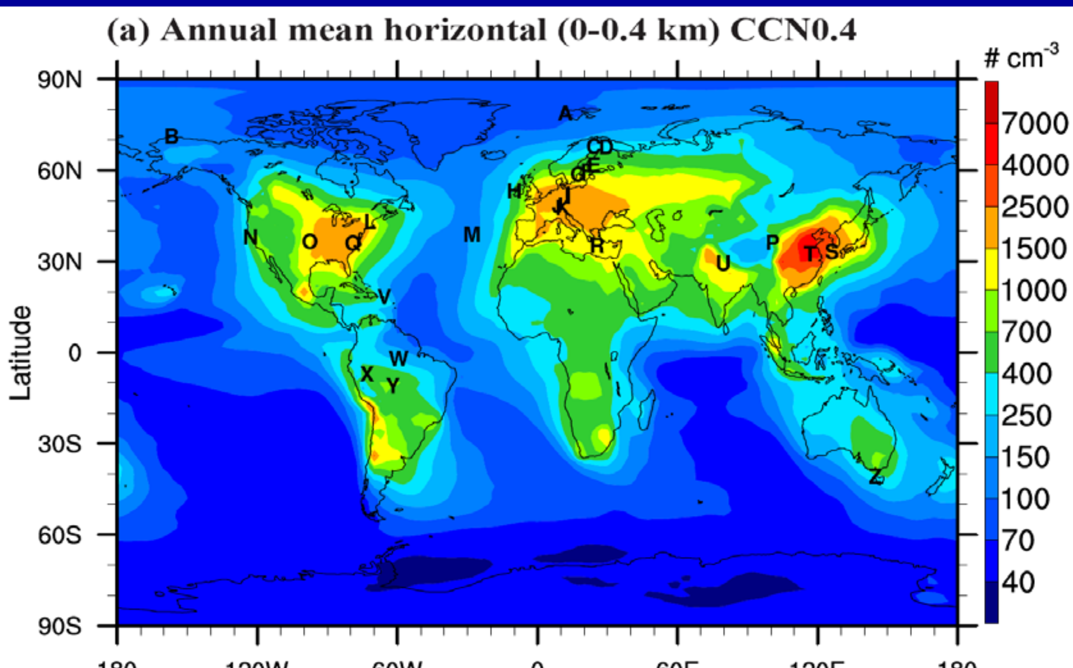
(Yu and Luo, 2009; Yu, 2011)

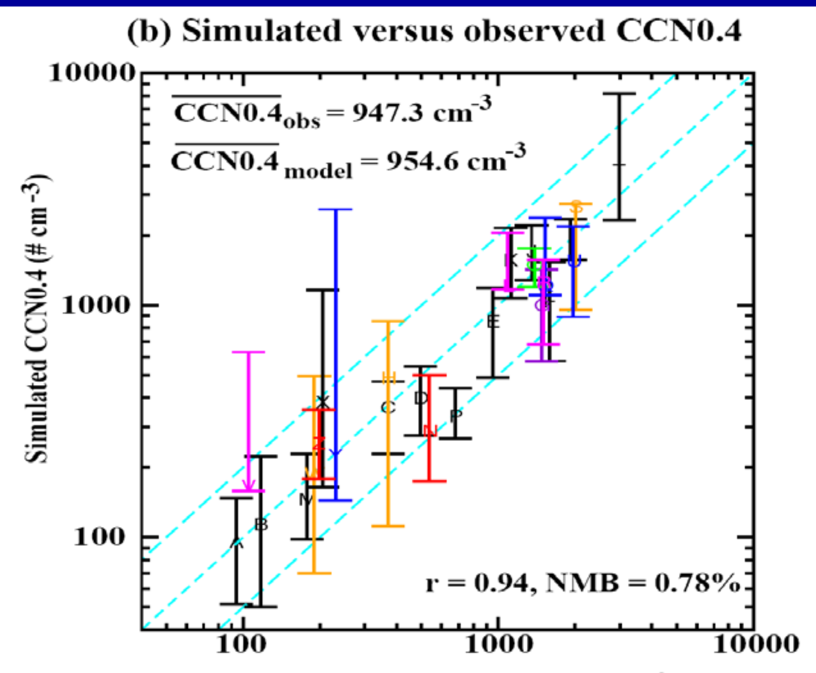






Yu and Luo, 2009; Luo and Yu, 2011.



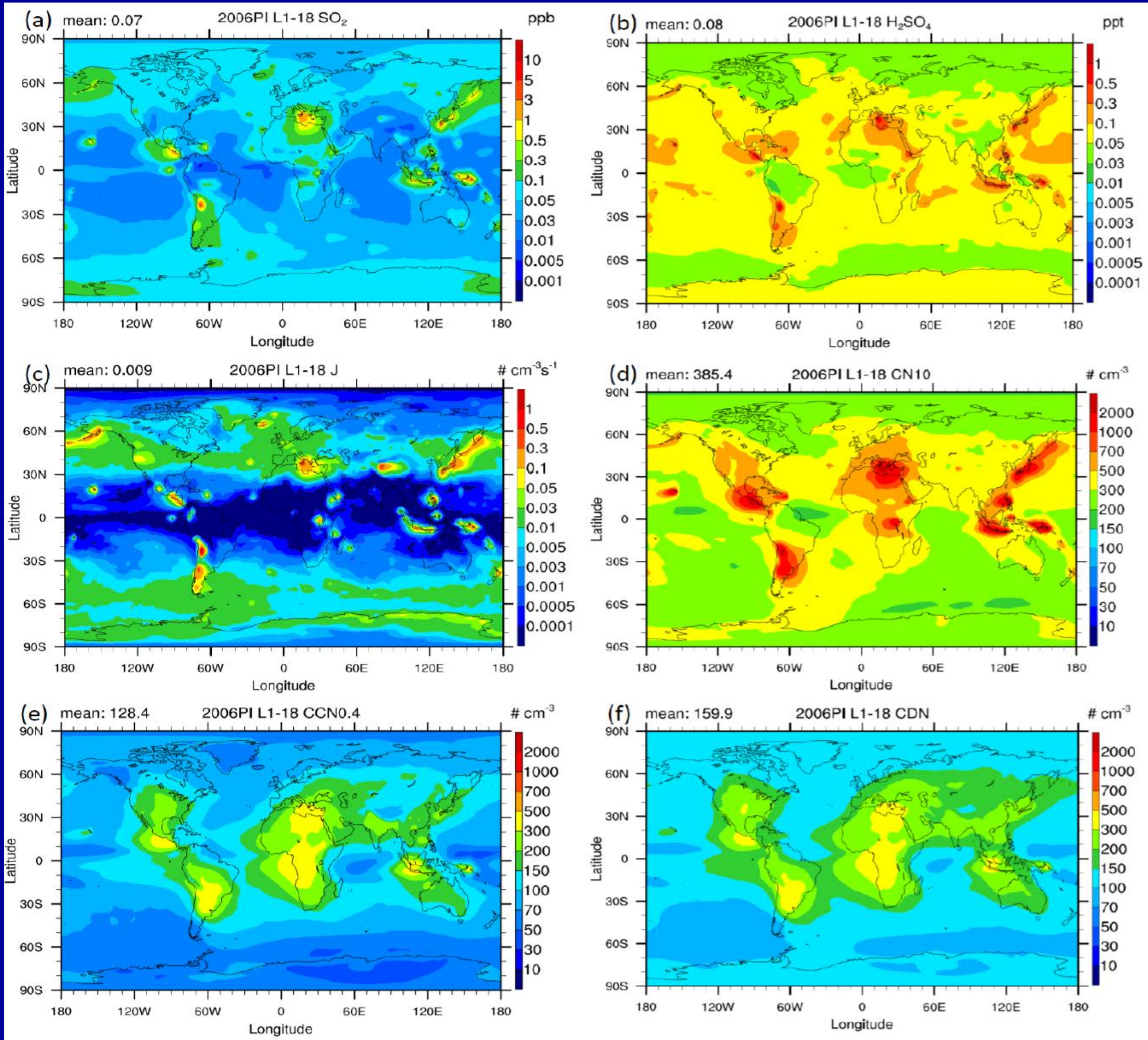


Yu et al., ACP, 2012.

Most data from Andreae, ACP, 2009.

PI emission

(i.e., No anthropogenic emissions)



Yu et al., 2013