Aerosol Particles: The Big Picture

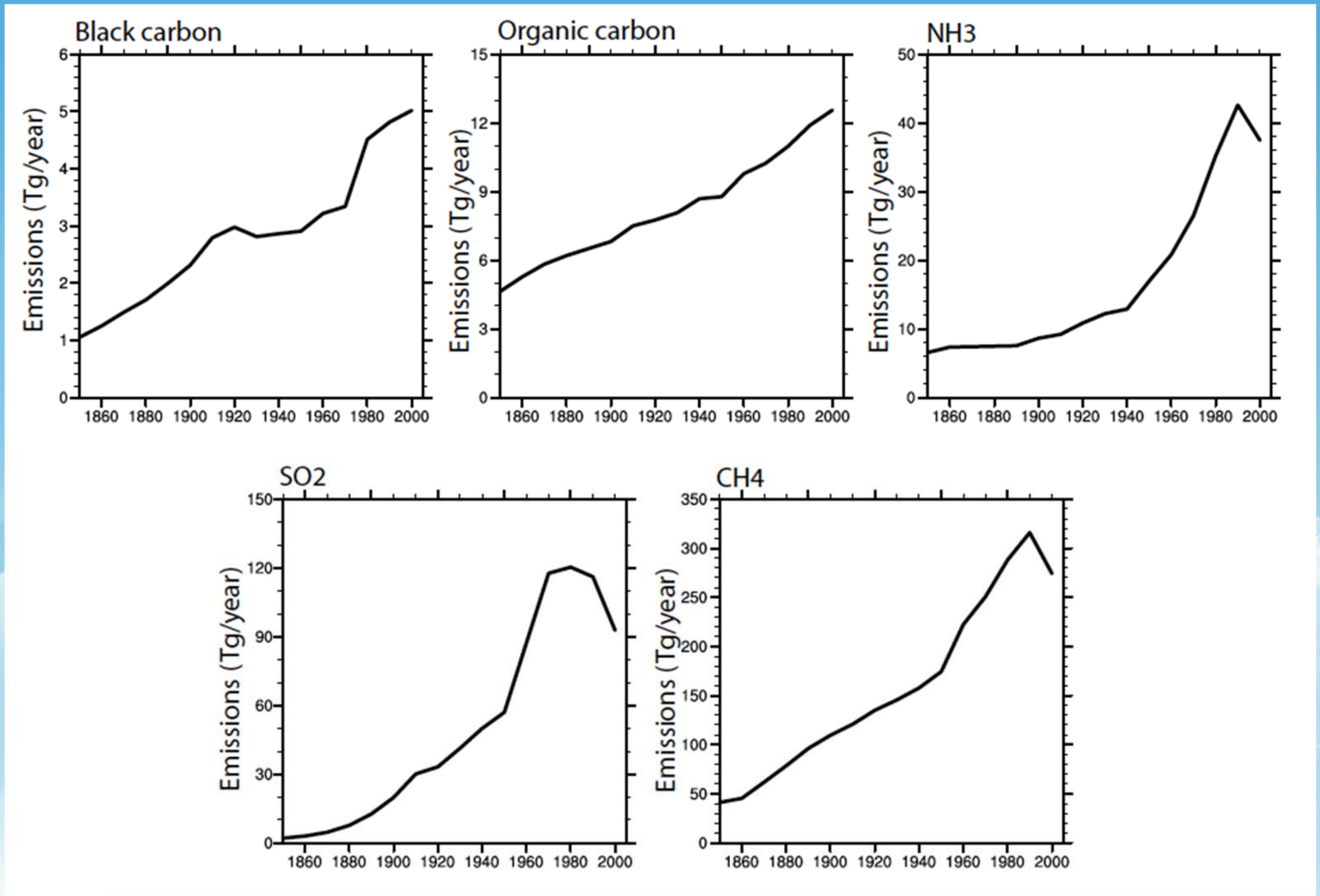
William D. Collins

Berkeley Lab and UC Berkeley
Berkeley, California
wdcollins@berkeley.edu

Topics

- Aerosol emissions and AOD since 1850
- The Coupled Model Intercomparison Project and simulation of historical aerosol trends
- Ensemble simulations of aerosols since 1850
- Range of aerosol properties across ensemble
- Implications of simulations for CMIP5

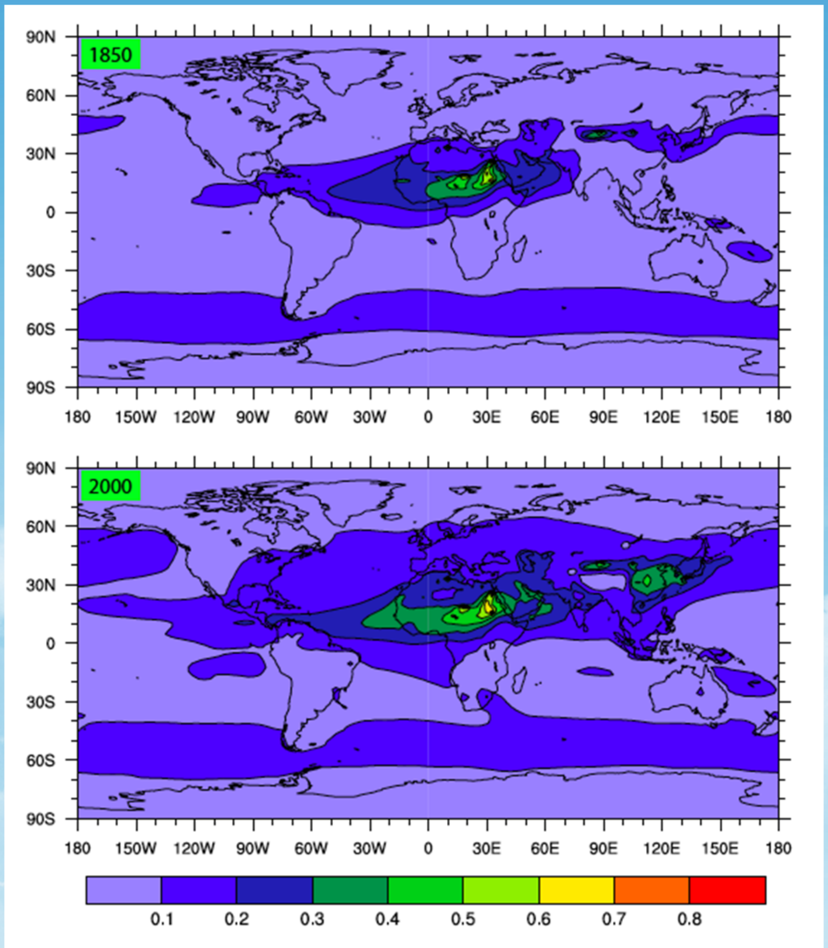
Historical Emission of Radiative Species



Lamarque et al, 2010

- Historical aerosol emissions have been developed for climate simulation.

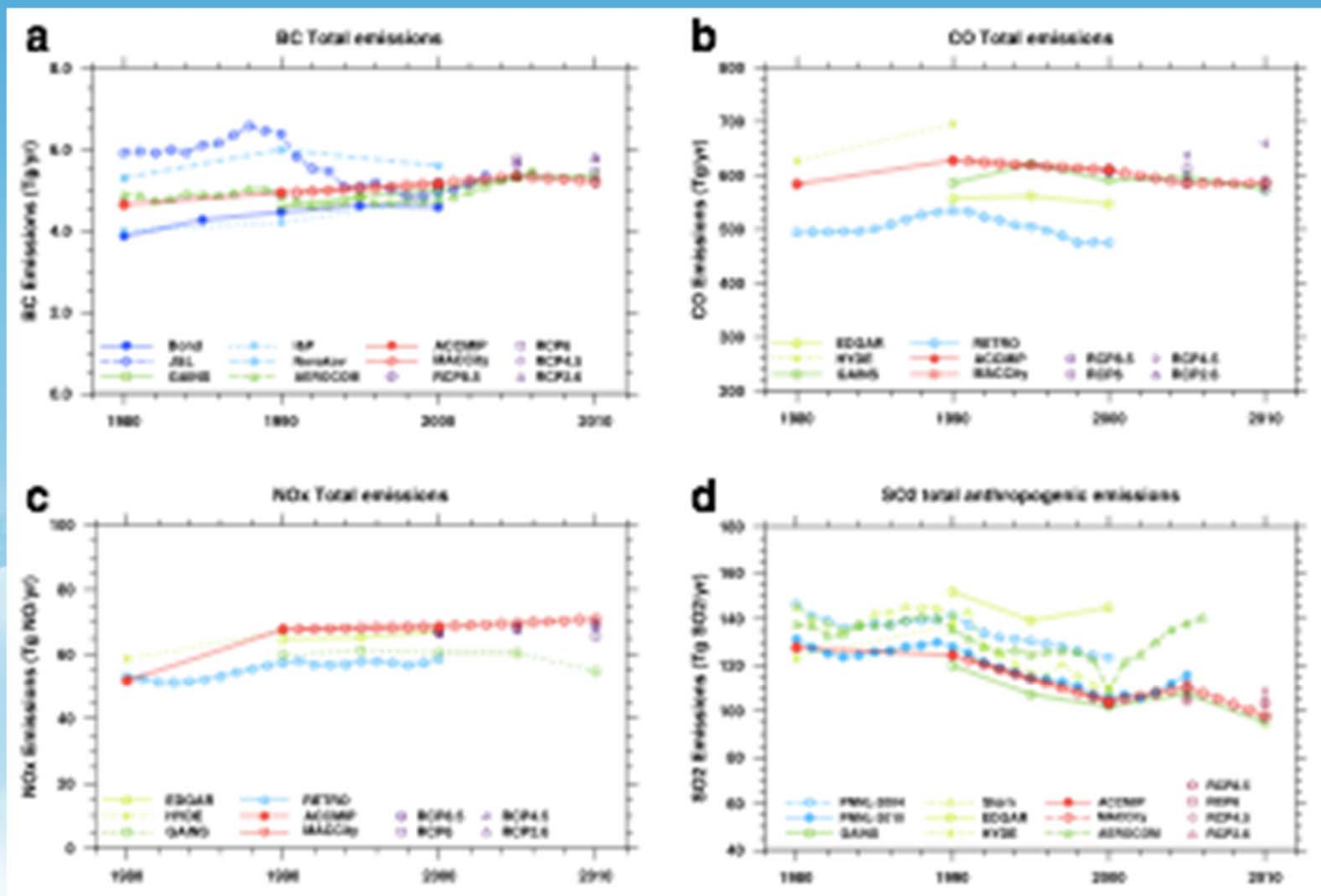
Historical Evolution of AOD



Lamarque et al, 2010

- The emissions produce significant increases in AOD across northern hemisphere.

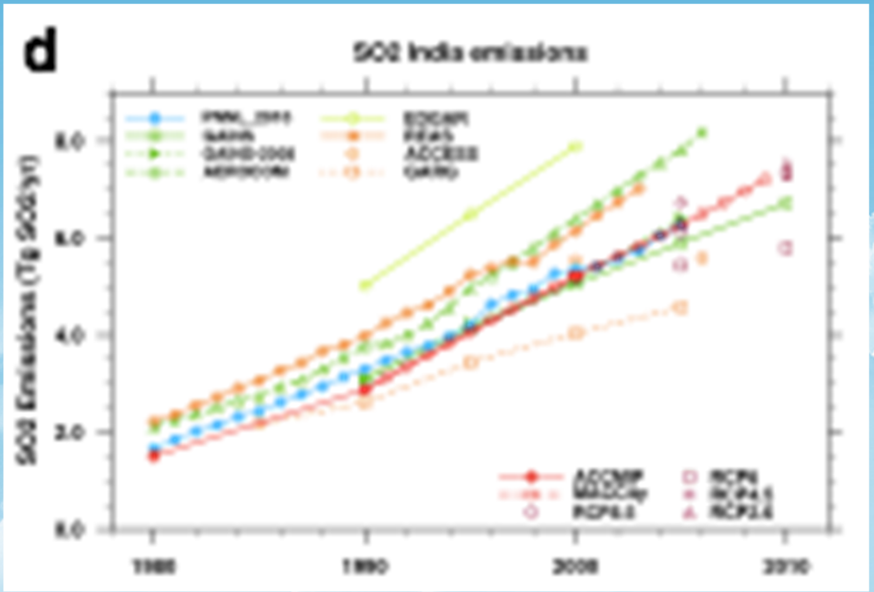
Recent Trends in Aerosol Emissions



Granier et al, 2011

- Global BC emissions have increased while SO_2 emissions have decreased since 1980.

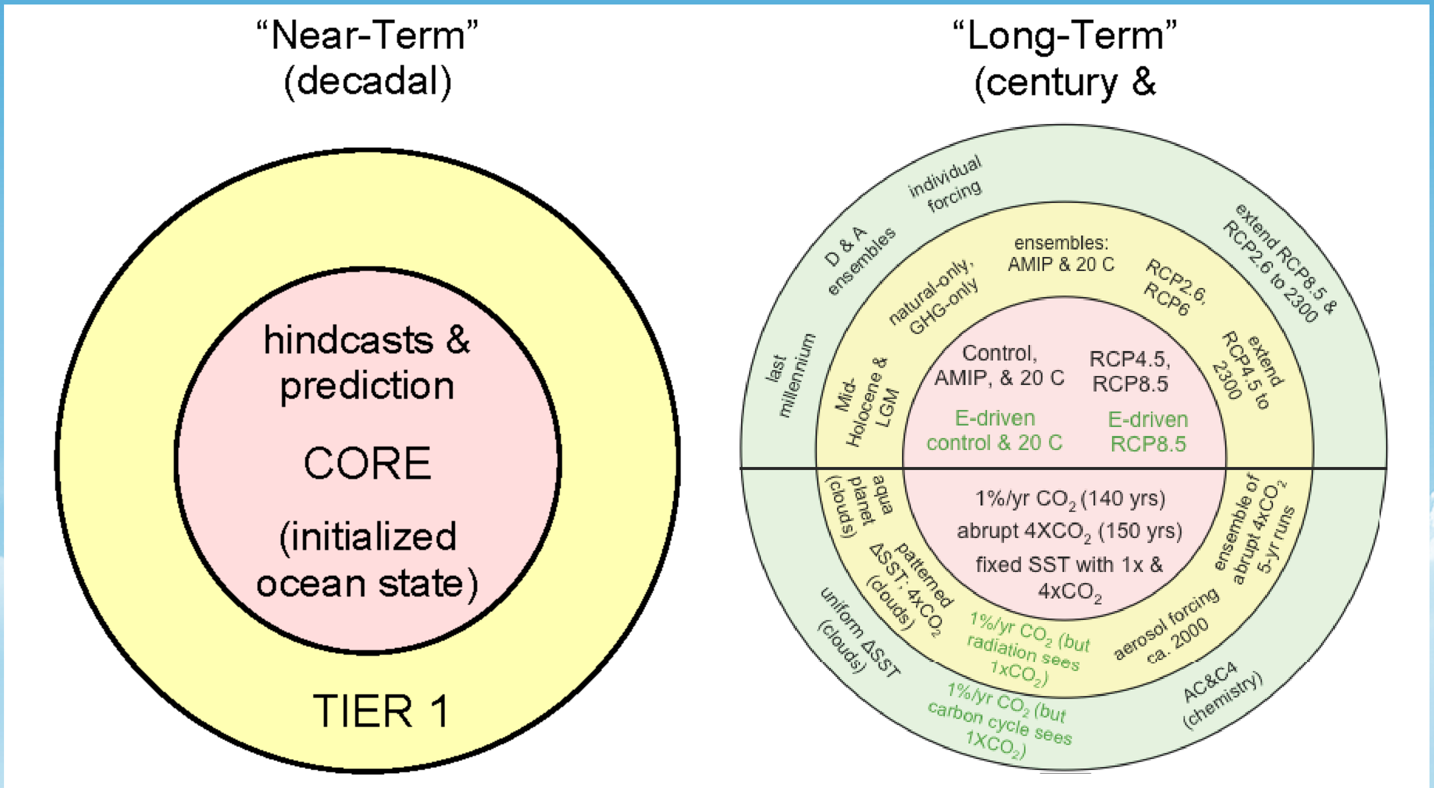
Recent Trends in SO_2 by Region



Granier et al, 2011

- The declining global emissions of SO_2 result from opposing regional trends.

The CMIP5 climate simulation protocol



Taylor et al, 2011

- The Coupled Model Intercomparison Protocol (CMIP5) is the basis for AR5.
- It includes a new set of simulations for the historical record: 1850 - 2005.

The CMIP5 Models

- To address process uncertainties, CMIP5 includes output from >22 different centers.
- Same forcings are used in these models for a uniform ensemble.

Modeling Center	Model	Institution	term of use
BCC	BCC-CSM1.1	Beijing Climate Center, China Meteorological Administration	unrestricted
CCCma	CanAM4 CanCM4 CanESM2	Canadian Centre for Climate Modelling and Analysis	unrestricted
CMCC	CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	non-commercial only
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	non-commercial only
CSIRO-BOM	ACCESS1.0 ACCESS1.3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	non-commercial only
CSIRO-QCCCE	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence	non-commercial only
EC-EARTH	EC-EARTH	EC-EARTH consortium	non-commercial only
GCESS	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	unrestricted
INM	INM-CM4	Institute for Numerical Mathematics	unrestricted
IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR	Institut Pierre-Simon Laplace	unrestricted
LASG-CESS	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University	unrestricted
LASG-IAP	FGOALS-gl FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	unrestricted
MIROC	MIROC4h MIROC5 MIROC-ESM MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	non-commercial only
MOHC	HadCM3 HadGEM2-A HadGEM2-CC HadGEM2-ES	Met Office Hadley Centre	unrestricted
MPI-M	MPI-ESM-LR MPI-ESM-MR MPI-ESM-P	Max Planck Institute for Meteorology (MPI-M)	unrestricted
MRI	MRI-AGCM3.2H MRI-AGCM3.2S MRI-CGCM3	Meteorological Research Institute	non-commercial only
NASA GISS	GISS-E2-H GISS-E2-R	NASA Goddard Institute for Space Studies	unrestricted
NASA GMAO	GEOS-5	NASA Global Modeling and Assimilation Office	unrestricted
NCAR	CCSM4	National Center for Atmospheric Research	unrestricted
NCC	NorESM1-M NorESM1-ME	Norwegian Climate Centre	unrestricted
NCEP	CFSv2-2011	National Centers for Environmental Prediction	unrestricted
NOAA GFDL	GFDL-CM2.1 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M GFDL-HIRAM-C180 GFDL-HIRAM-C360	Geophysical Fluid Dynamics Laboratory	unrestricted

Representative Concentration Pathways (RCPs)

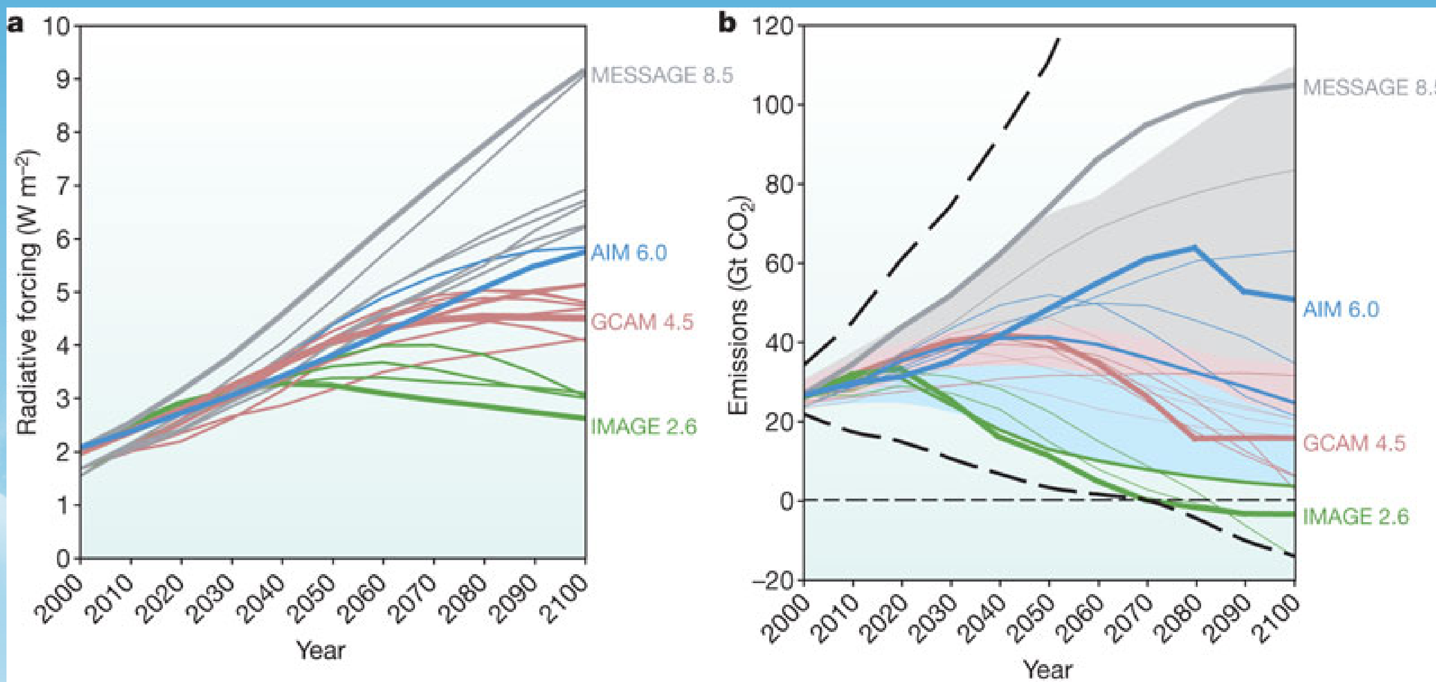
Name	Radiative forcing	Concentration(p.p.m.)	Pathway	Model providing RCP*	Reference
RCP8.5	>8.5Wm^{-2} in 2100	>1,370 CO_2-equiv. in 2100	Rising	MESSAGE	55, 56
RCP6.0	~6Wm^{-2} at stabilization after 2100	~850 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	AIM	57, 58
RCP4.5	~4.5Wm^{-2} at stabilization after 2100	~650 CO_2-equiv. (at stabilization after 2100)	Stabilization without overshoot	GCAM	48, 59
RCP2.6	Peak at ~3Wm^{-2} before 2100 and then declines	Peak at ~490 CO_2-equiv. before 2100 and then declines	Peak and decline	IMAGE	60, 61

***MESSAGE, Model for Energy Supply Strategy Alternatives and their General Environmental Impact, International Institute for Applied Systems Analysis, Austria; AIM, Asia-Pacific Integrated Model, National Institute for Environmental Studies, Japan; GCAM, Global Change Assessment Model, Pacific Northwest National Laboratory, USA (previously referred to as MiniCAM); IMAGE, Integrated Model to Assess the Global Environment, Netherlands Environmental Assessment Agency, The Netherlands.**

Moss et al, 2010

- The RCPs include several mitigation scenarios with range of 2100 forcings.
- The RCP emissions are harmonized with the historical emissions.

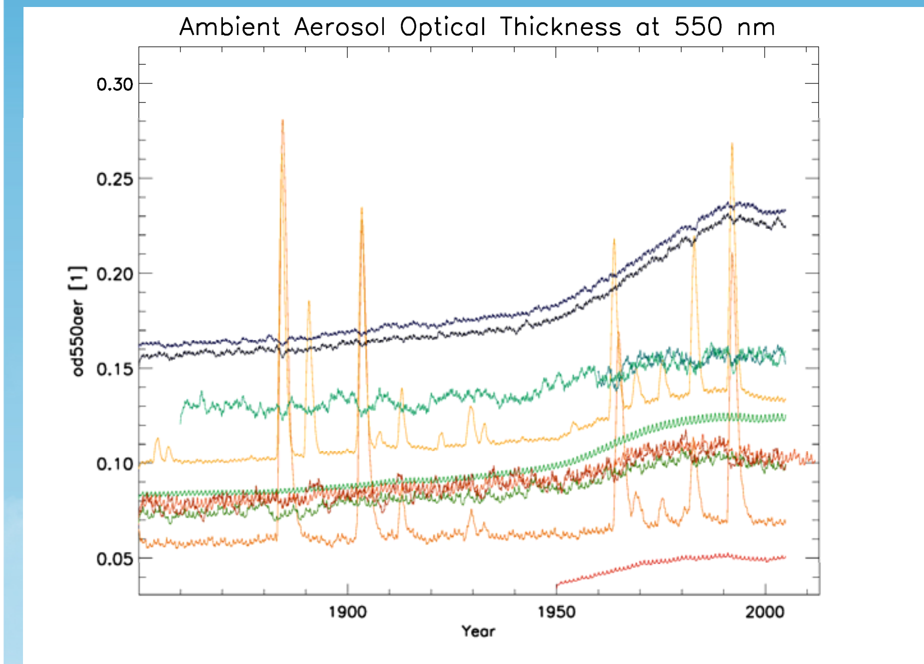
Radiative Forcing and CO_2 in the RCPs

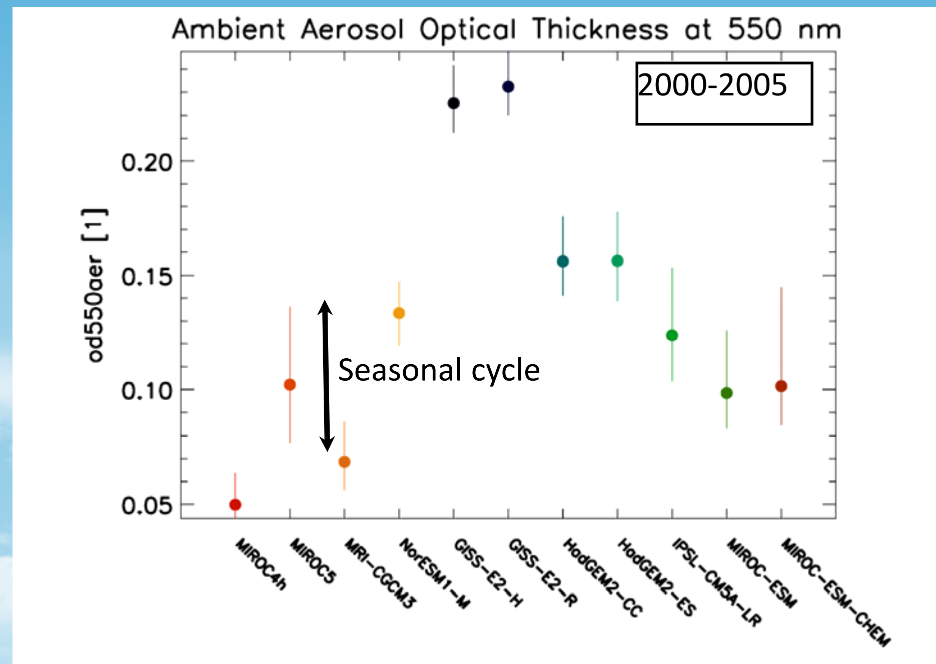


Moss et al, 2010

- Consistency in GHG+aerosol forcing is a key element of CMIP5 design.
- Roughly 2/3 to 3/4 of warming to 2025 is due to historical emissions.
- We have analyzed ~15 models available now in CMIP5 archives.

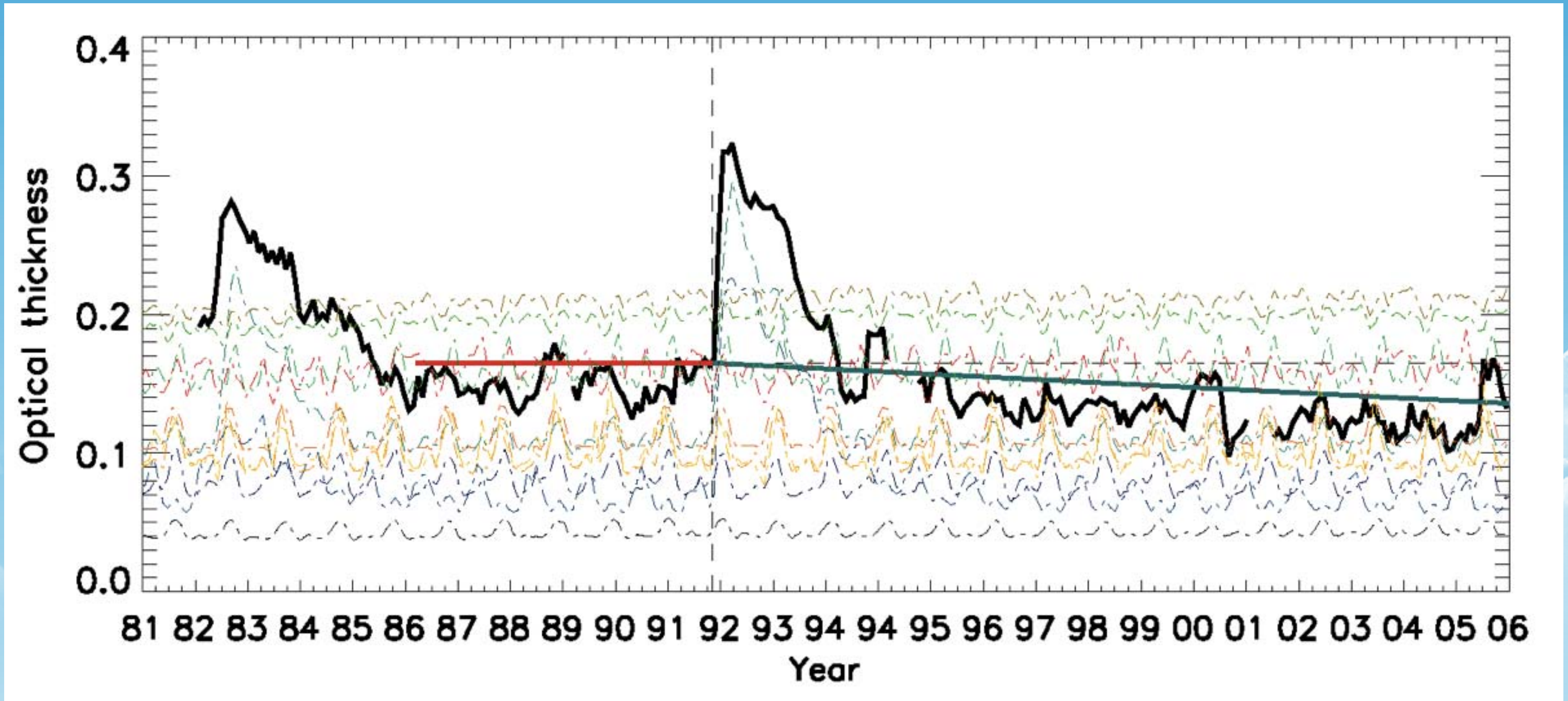
Present-Day Aerosol Optical Depth





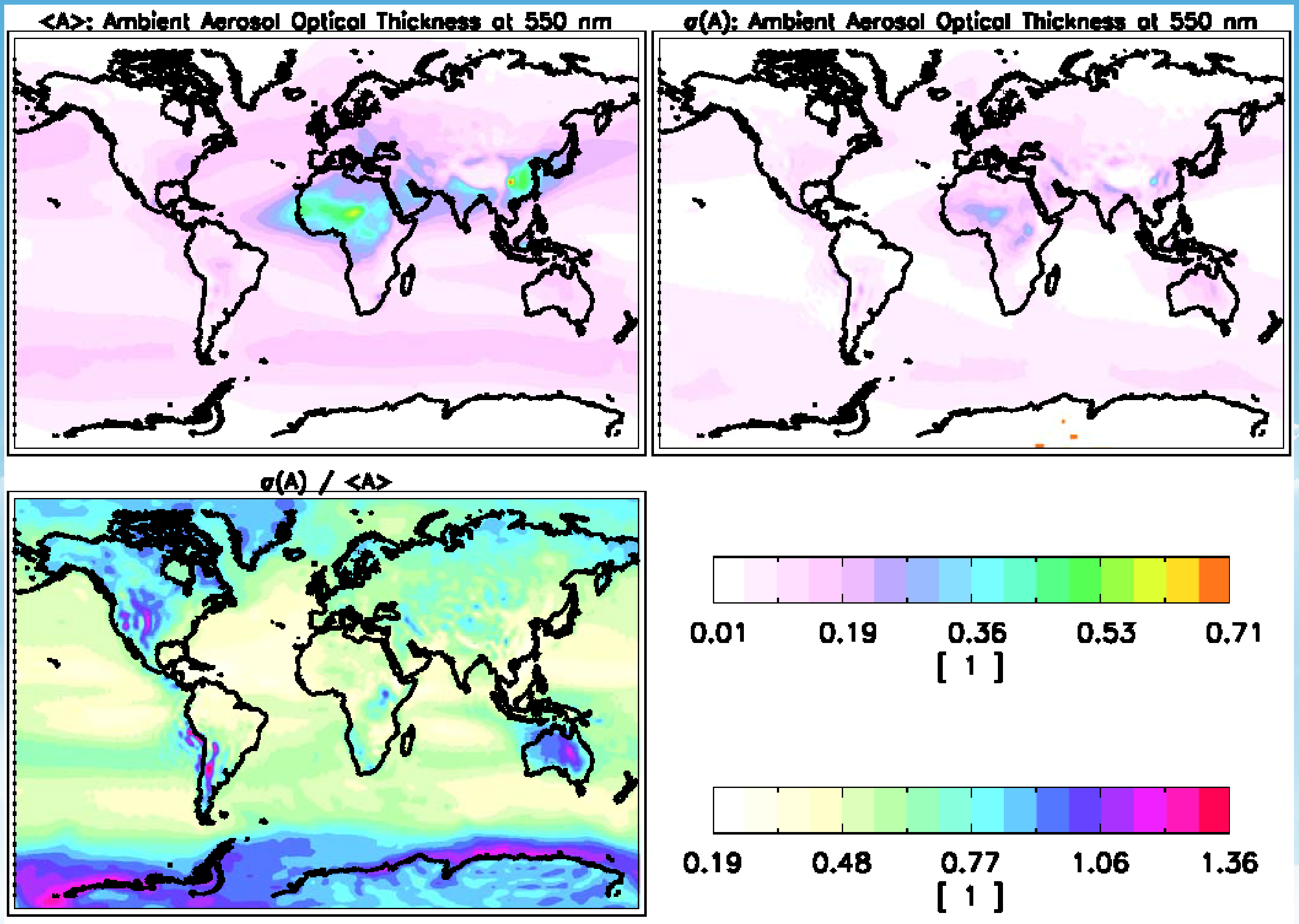
- AOD for all species has differed since start of simulations in 1850.
- Current AODs vary across ensemble by factor of >4.
- Resulting variation in clear-sky direct forcing is O(5 W/m^2).

Comparison of CMIP5 AODs vs GACP

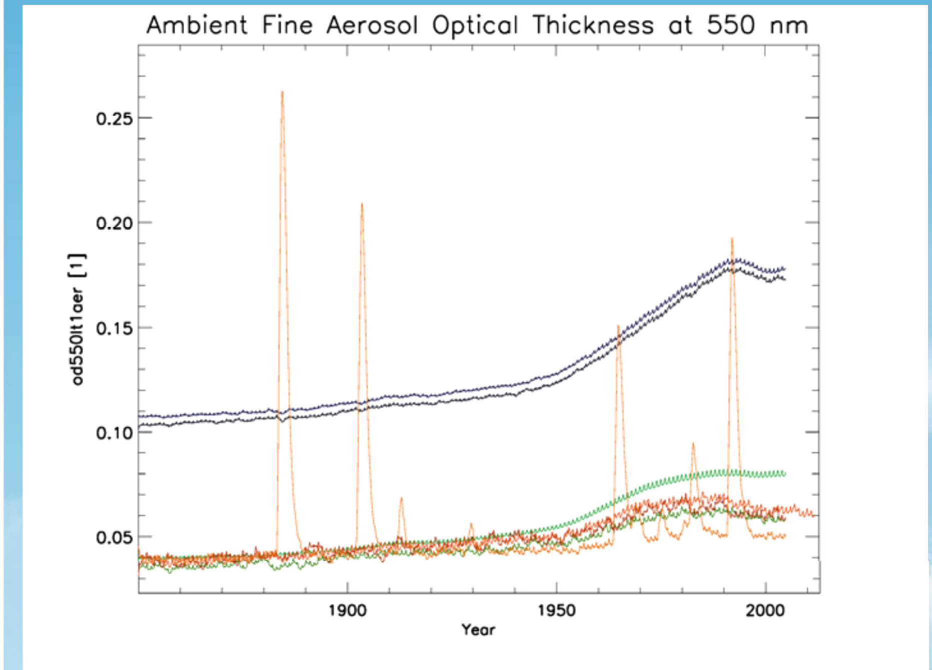


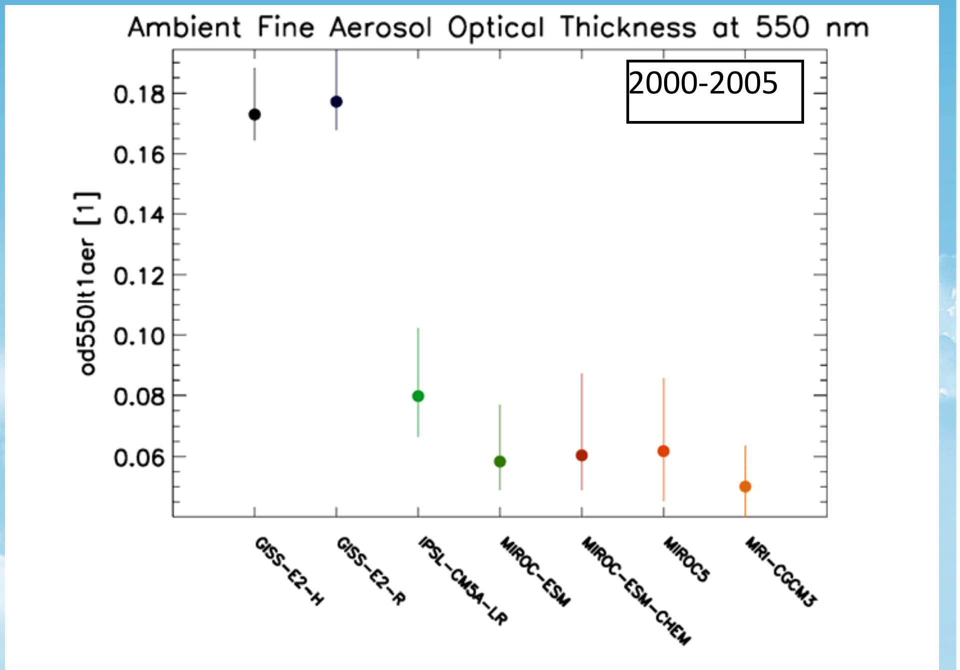
- Compared to earlier global AOD retrievals, modeled AOD trends are ~0.
- Little evidence in simulations for global brightening manifested in AOD.
- This is consistent with recent assimilation-quality MODIS retrievals.

Ensemble AOD for 2000-2005



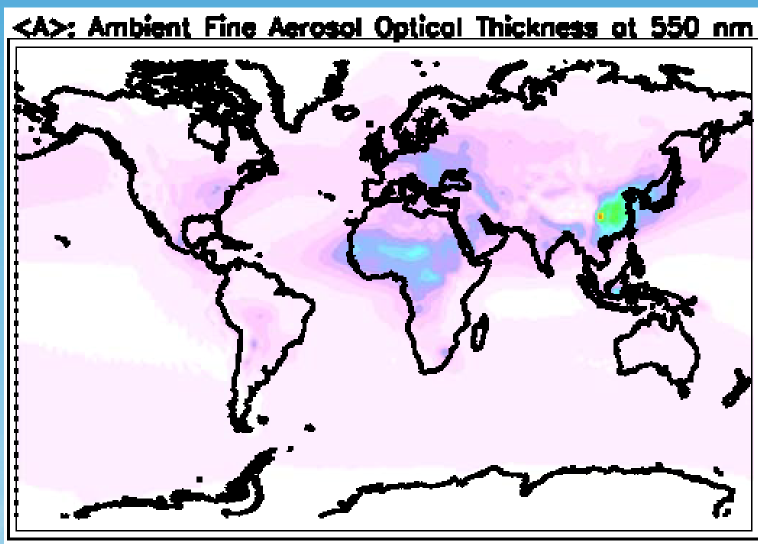
AOD for Particles < 1 µm



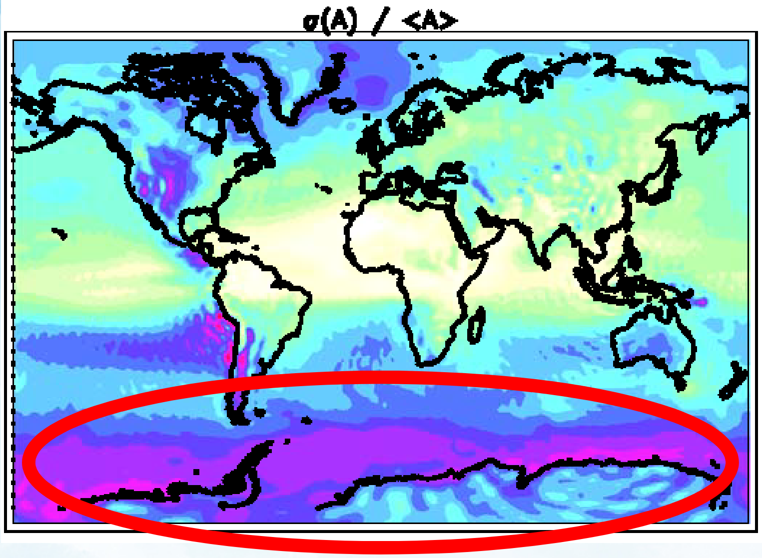


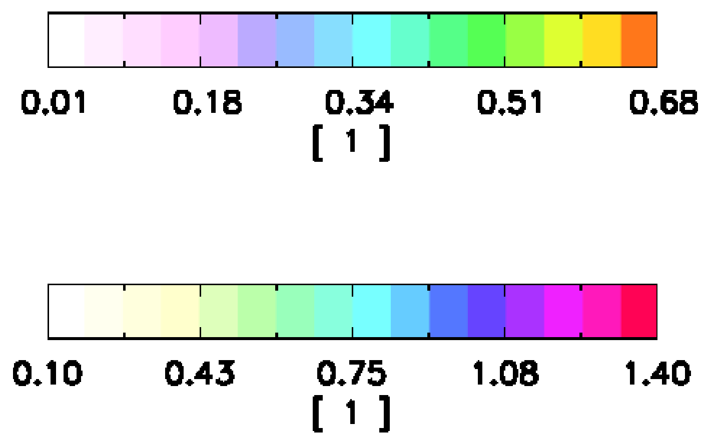
- Estimates of fine-mode fraction of AOD differ by factor of ~3.
- The differences persist over time span of the simulations.

Ensemble Fine-Mode AOD

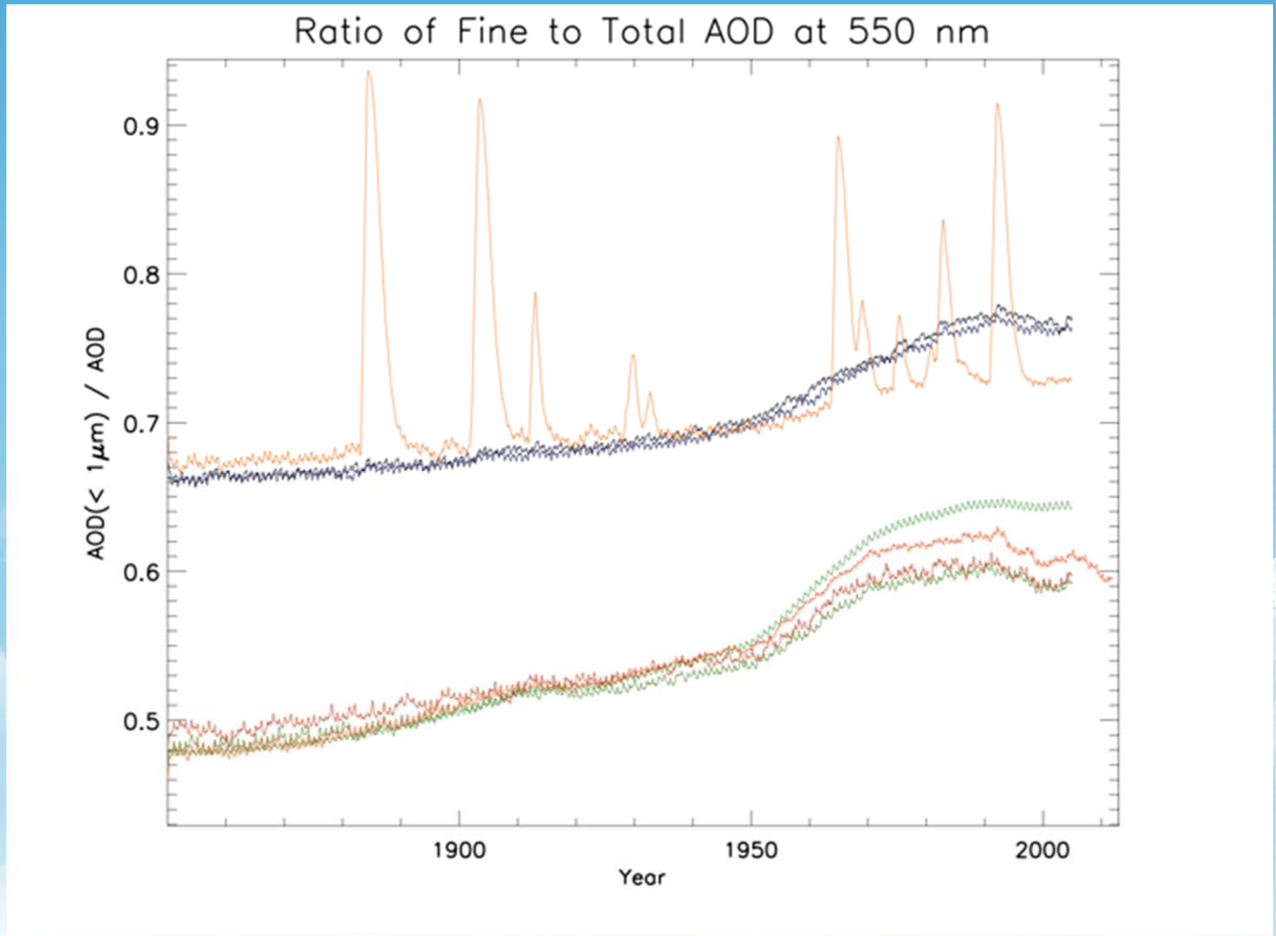


The largest relative variability occurs in remote regions, e.g., Pacific Ocean near Antarctica



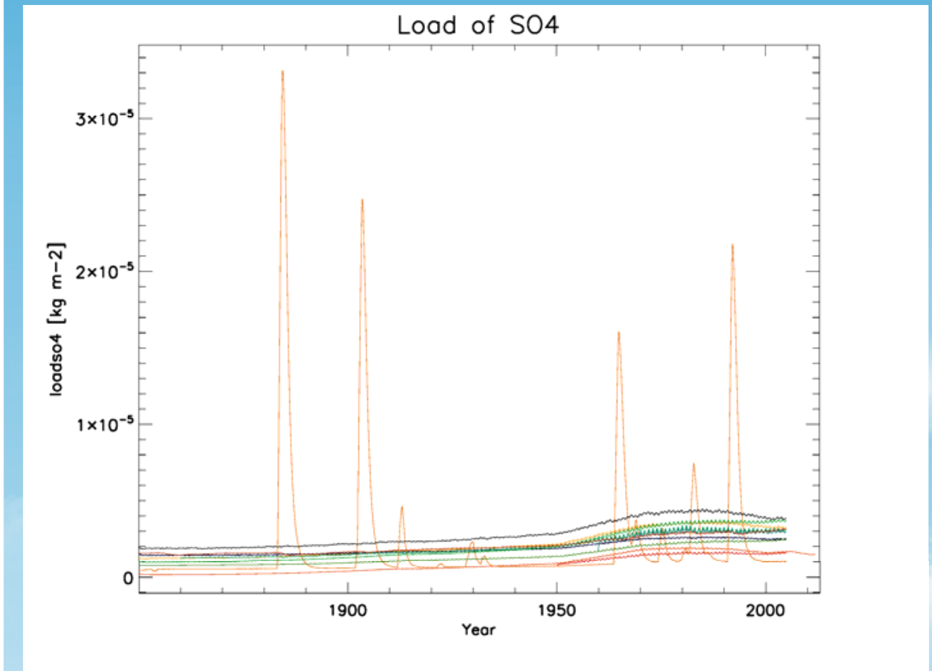


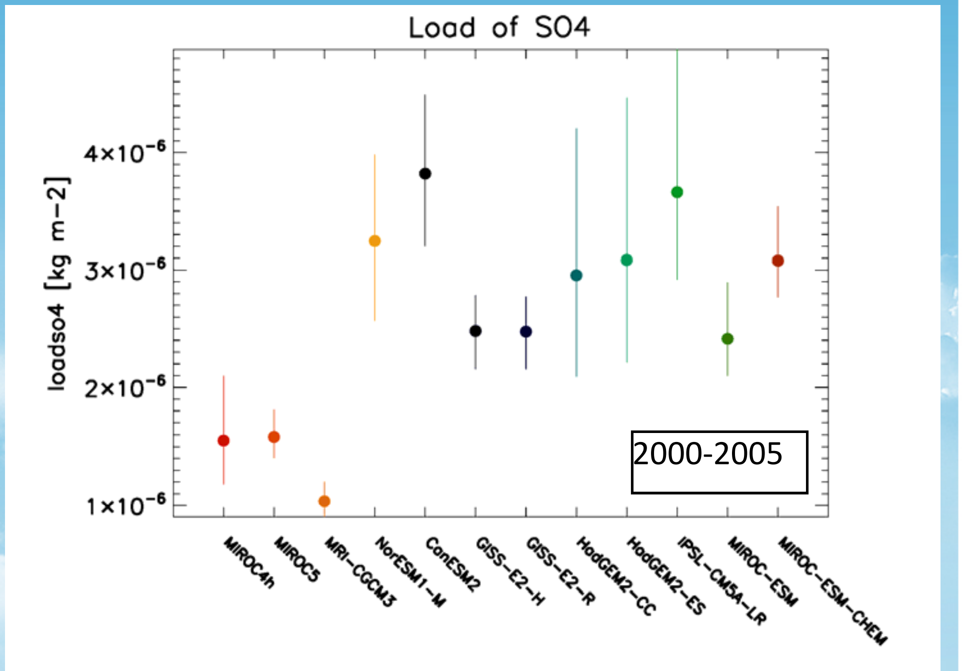
Fraction of AOD in Fine Mode < 1 μm



- There are ≥2 clusters of aerosol microphysical representations.
- These clusters may contain different fractions of anthropogenic aerosols.
- However, differences are greatest for lowest anthropogenic emissions.

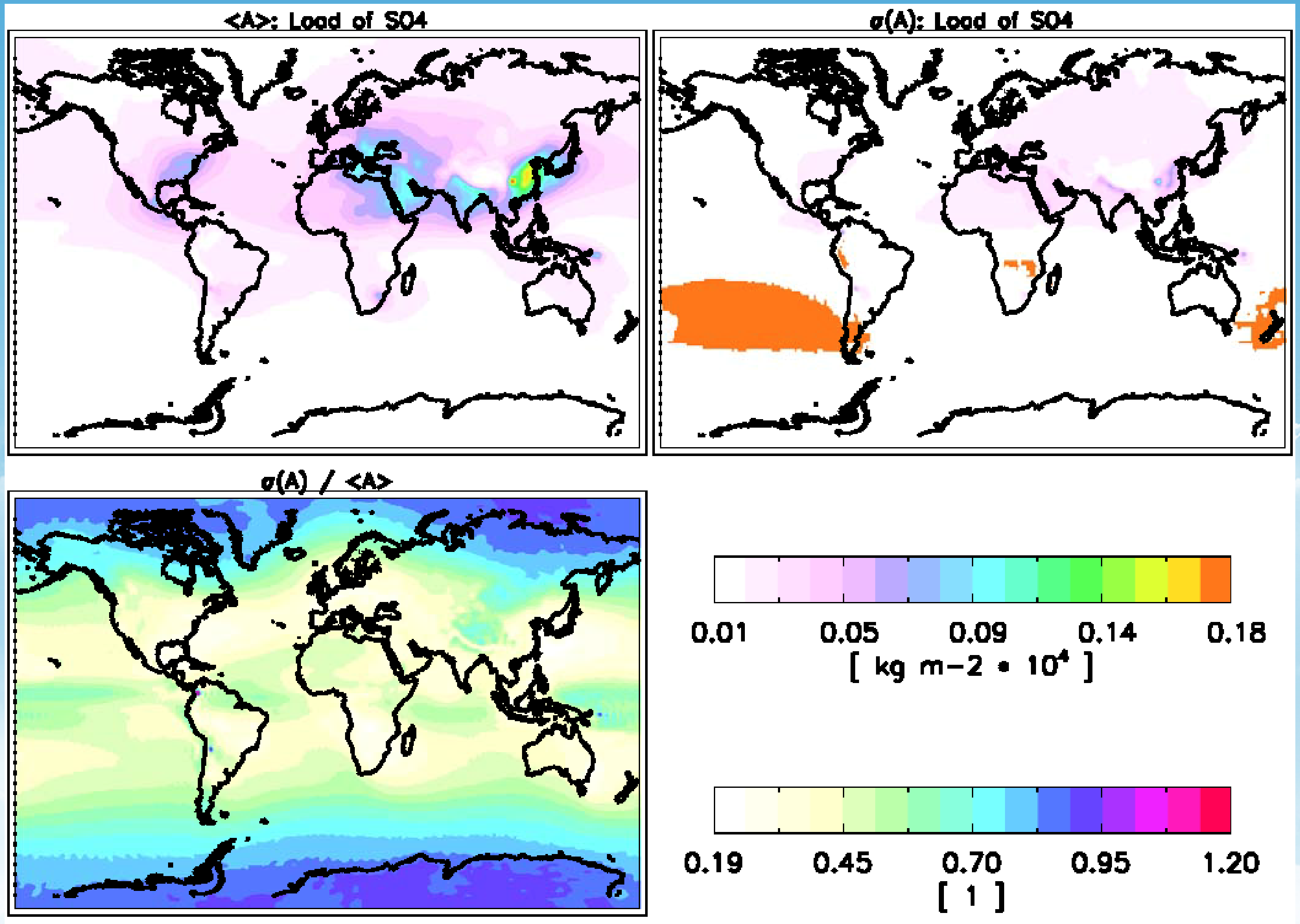
Load of SO_4



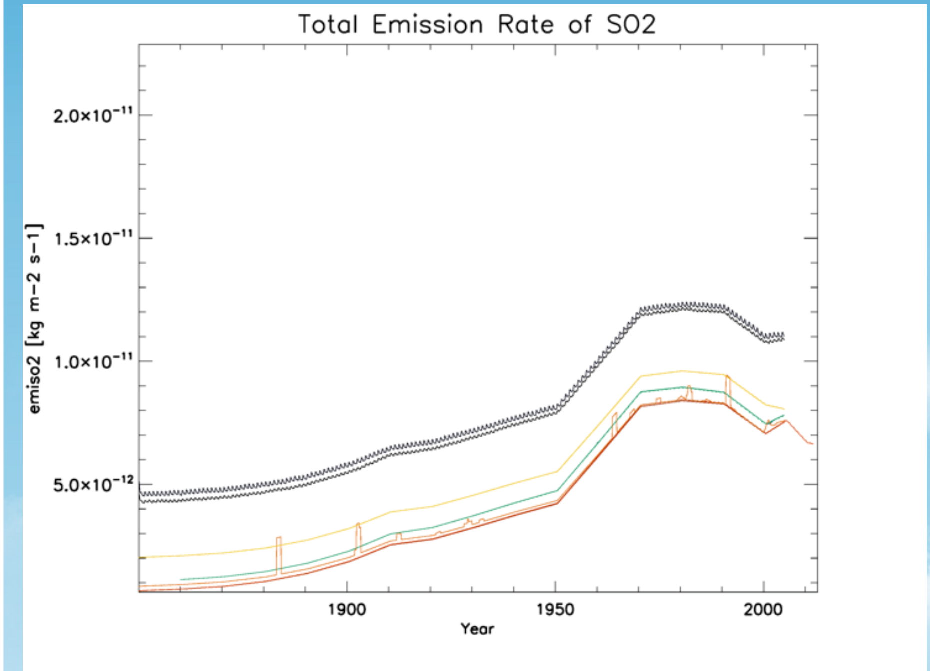


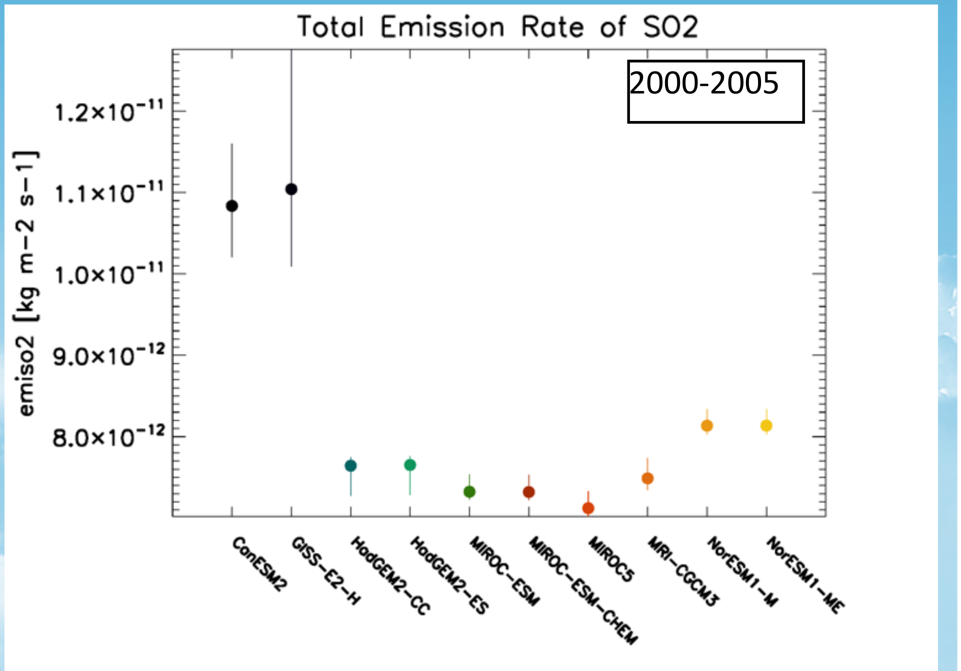
- Despite supposedly common emissions data, SO_4 loads vary by factor of ~3.
- There are also large variations in the seasonal cycle magnitude.

Ensemble Load of SO_4



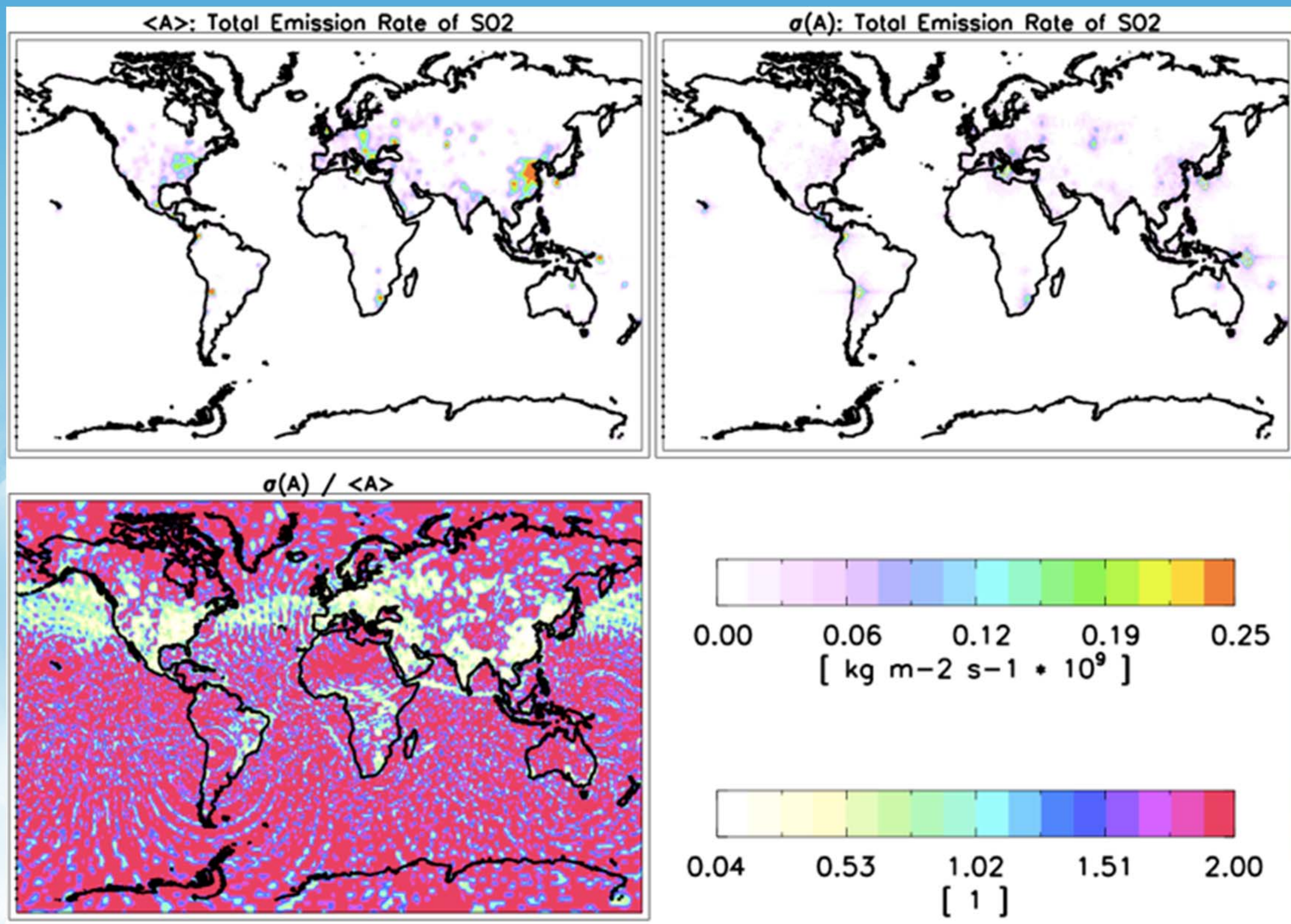
Emissions of SO_2



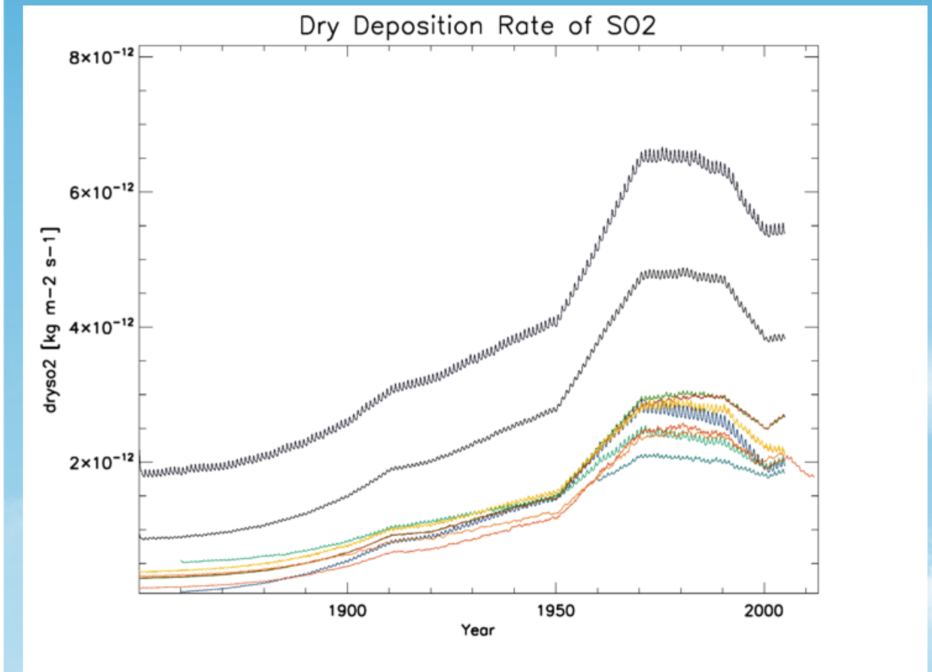


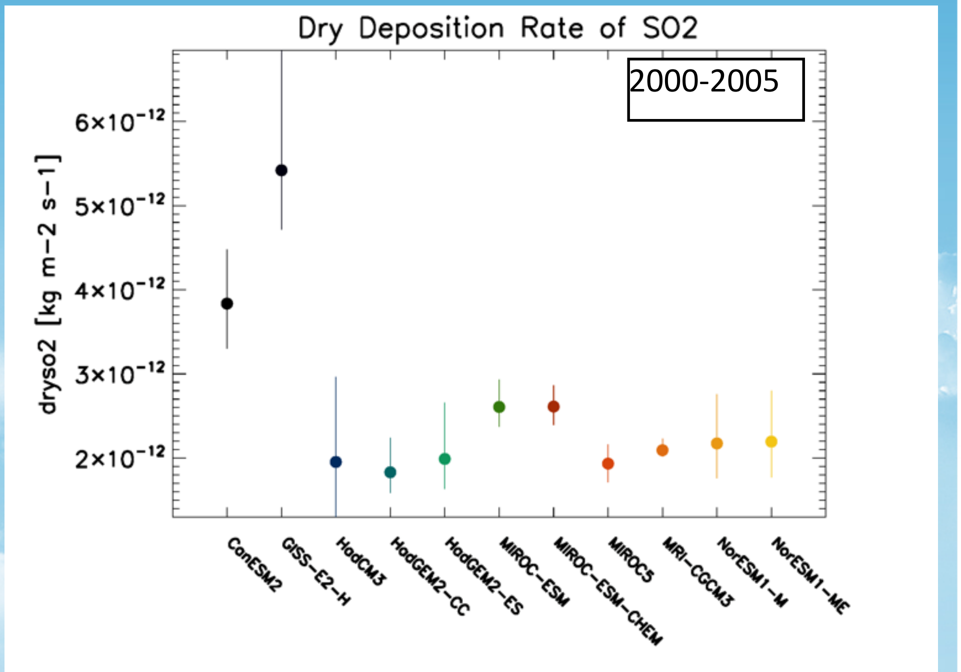
- There are ~33% differences in SO_2 emissions for present day.
- This explains a small fraction of variation in SO_4 loads across ensemble.

Ensemble Emissions of SO_2



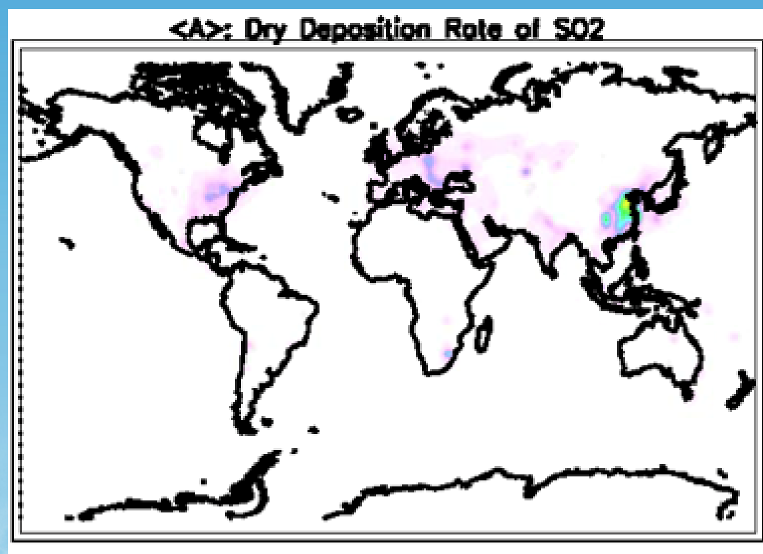
Dry Deposition of SO_2



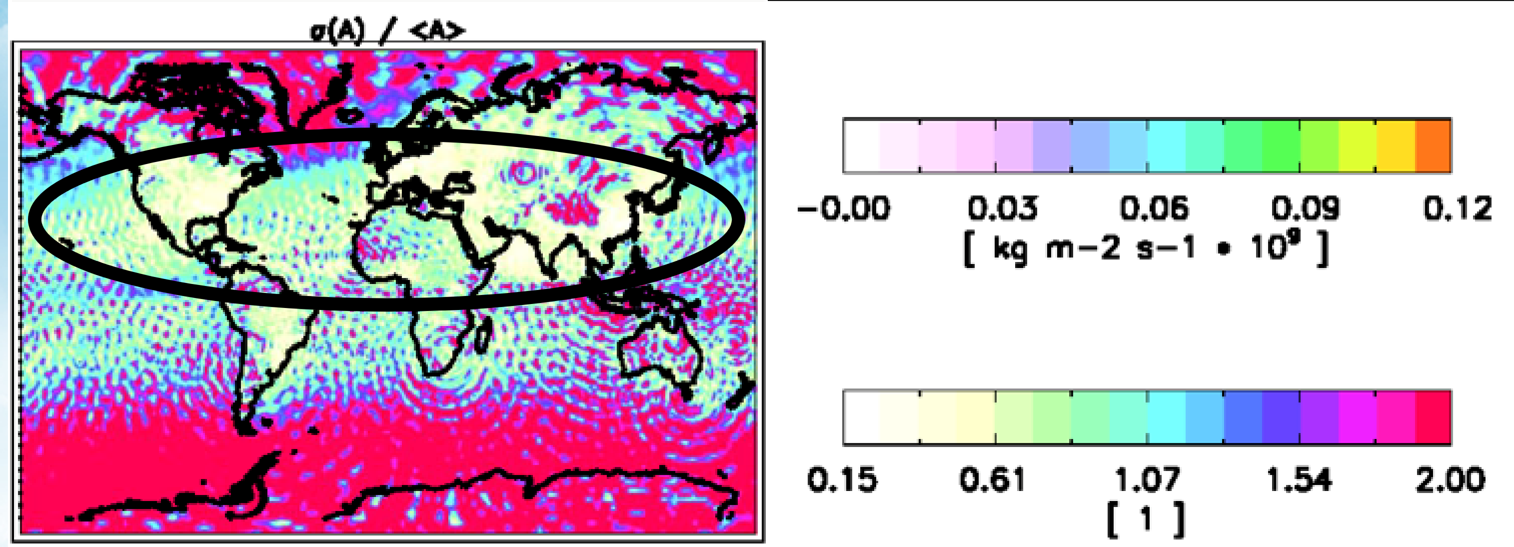


- Most models analyzed to date have similar rates of dry deposition.

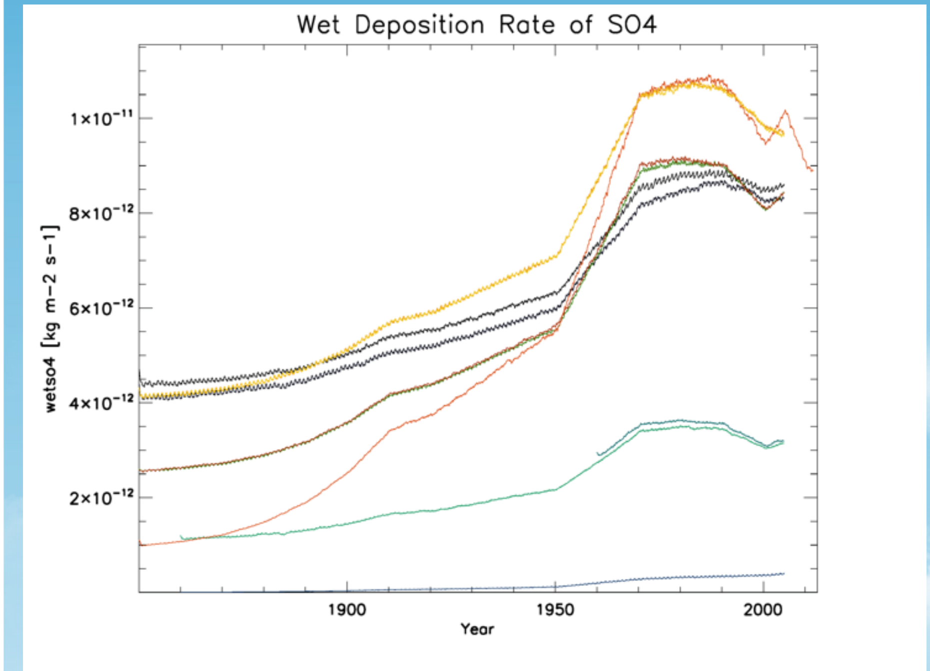
Ensemble Dry Deposition of SO_2

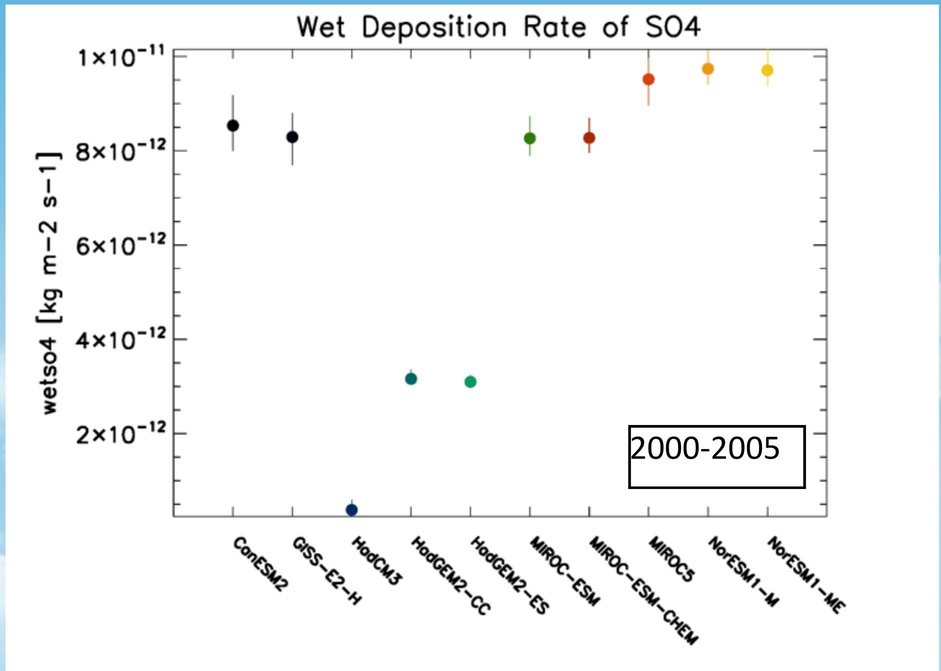


The smallest relative variability occurs in source regions.



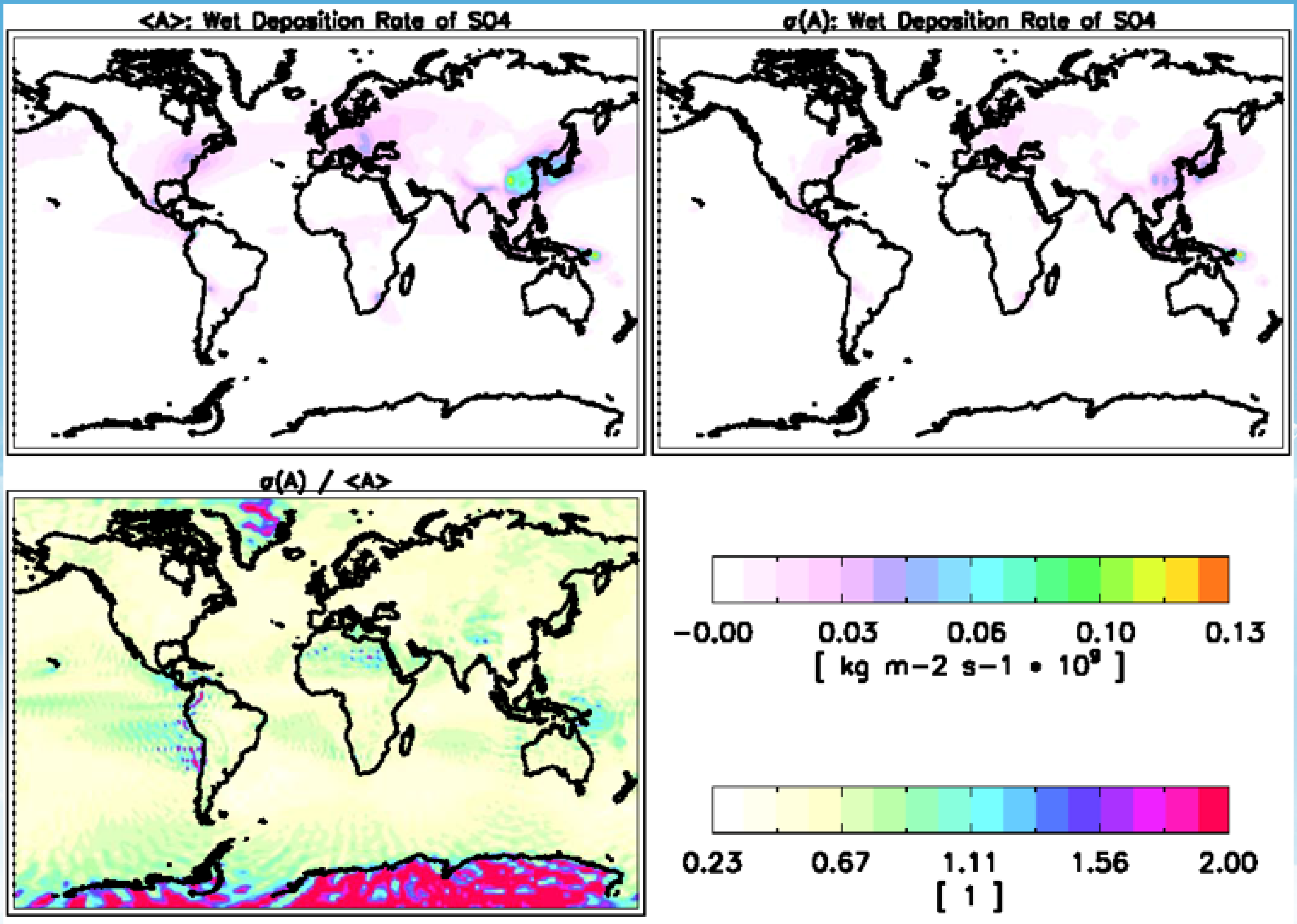
Wet Deposition of SO_4



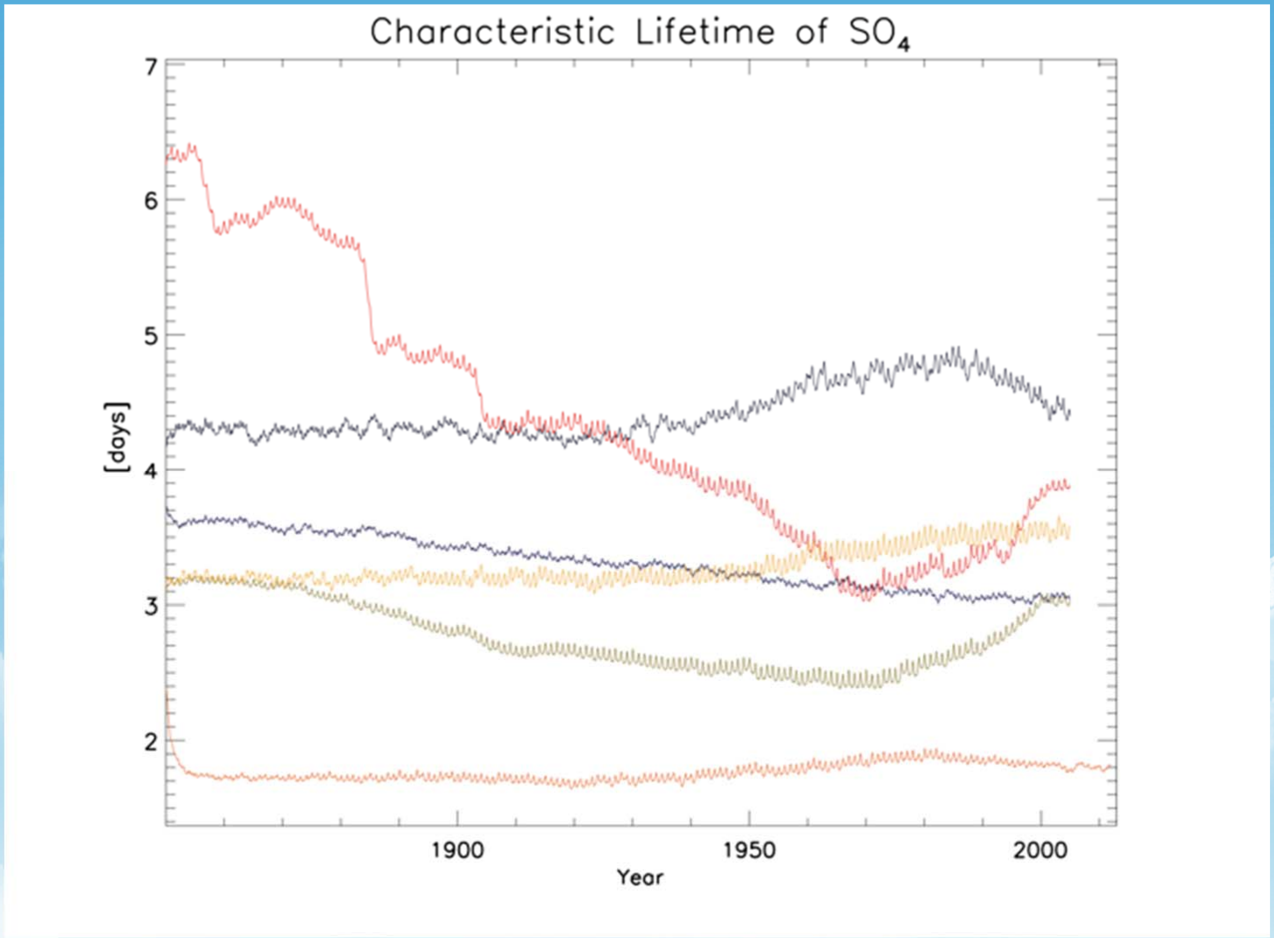


- In contrast to dry deposition, wet deposition varies by factor of >10.
- Seasonal cycle in wet deposition generally << cycle in dry deposition.

Ensemble Wet Deposition of SO_4

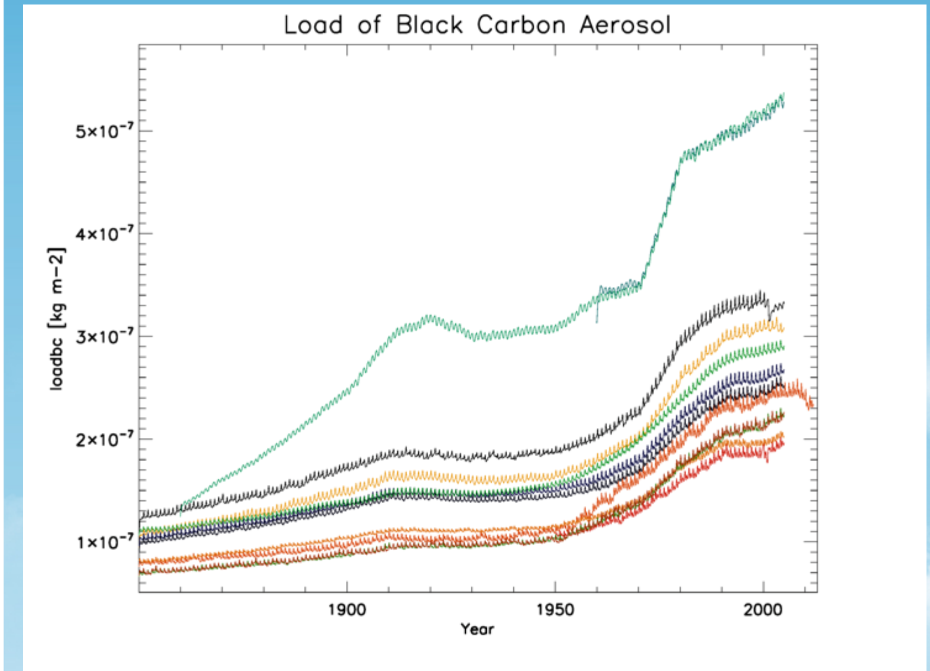


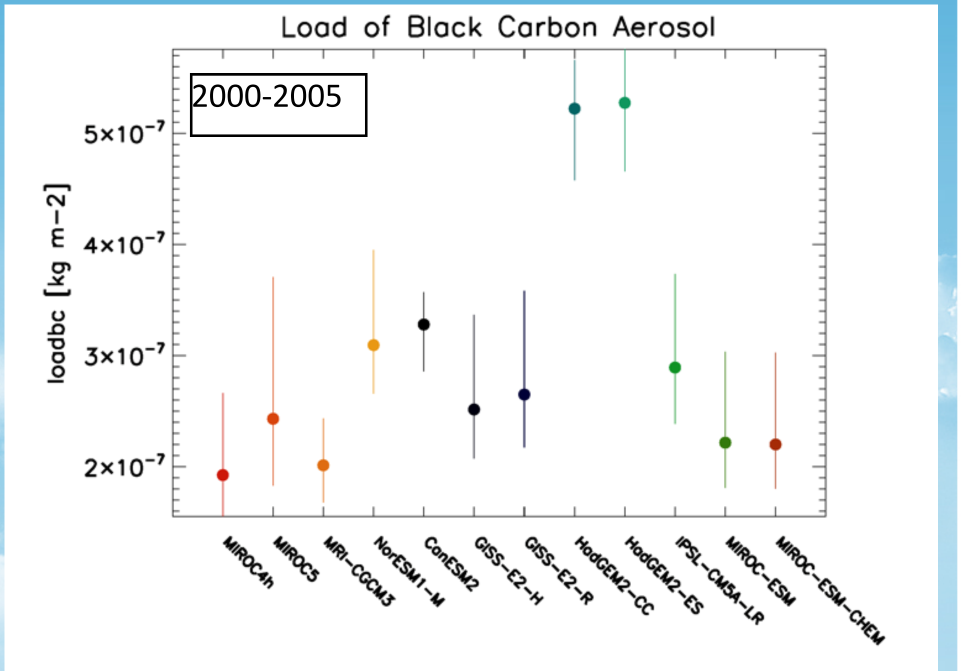
Characteristic Lifetime of SO_4



- Characteristic lifetime of SO_4 is estimated by t ~ load / (wet + dry sinks).
- Range of t varies by factors of 3 in 1950s to 2 in early 2000s.

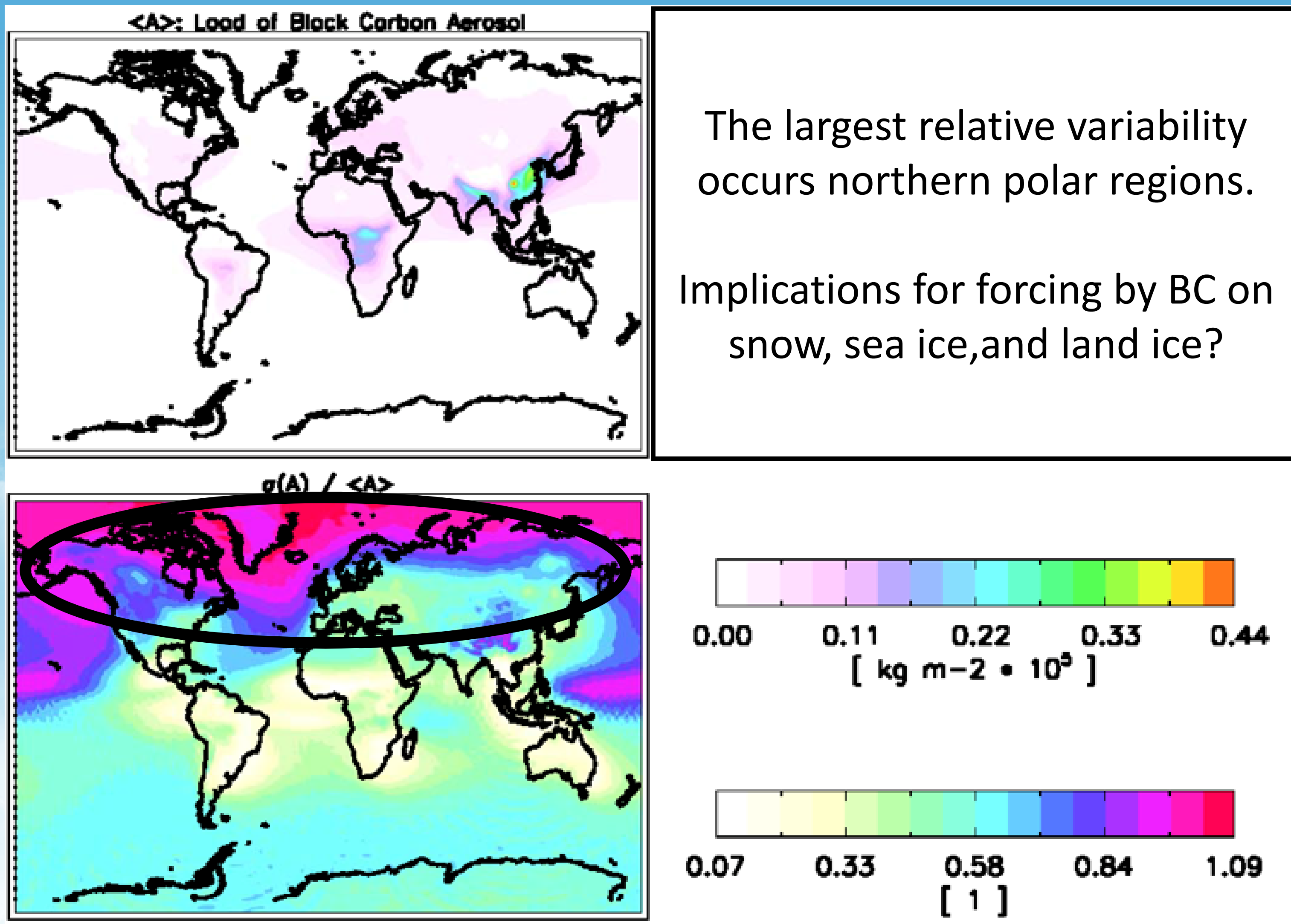
Load of Black Carbon





- Most models share similar loads of black carbon aerosols for present day.
- This reflects the more complete specification of species in RCPs and historical BCs.

Ensemble Load of Black Carbon



The largest relative variability occurs northern polar regions.

Implications for forcing by BC on snow, sea ice,and land ice?

Conclusions

- The CMIP5 simulations are broadly consistent with historical emissions.
- In improvement to CMIP3, emissions and AOD are continuous at present day.
- There is considerable diversity in the simulated aerosol properties, including:
  - Aerosol optical depth
  - Fraction of optical depth in fine mode (< 1 µm)
  - Load of sulphate aerosol
  - Characteristic lifetime of sulphate aerosol
  - Transport of anthropogenic aerosols to polar regions, esp. the Arctic.
- This diversity imply the aerosol forcing in historical simulations is not uniform.
- The differences will carry forward into decadal projections of climate change.