Some Model-Predicted Consequences of Regional and Sectoral Aerosol Reductions

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Objectives

What are the potential benefits (to air quality and to climate) of reducing aerosol emissions from particular

a) regions?

and

b) sectors?

To what extent can one infer quantities such as aerosol burden and forcing from emissions (without using a global model)?

Approach

We use the GISS GCM, with on-line aerosol (mass) for species:

sulfate (scatters)

black carbon (absorbs and scatters)

organic carbon (mostly scatters)

The aerosol simulation includes emissions, gas and aqueous phase chemistry, wet and dry deposition, transport, radiation (including water uptake for sulfate and organic carbon). We carry aerosol mass and assume the aerosols are externally mixed. We assume fixed SST's. We consider direct radiative forcing only.

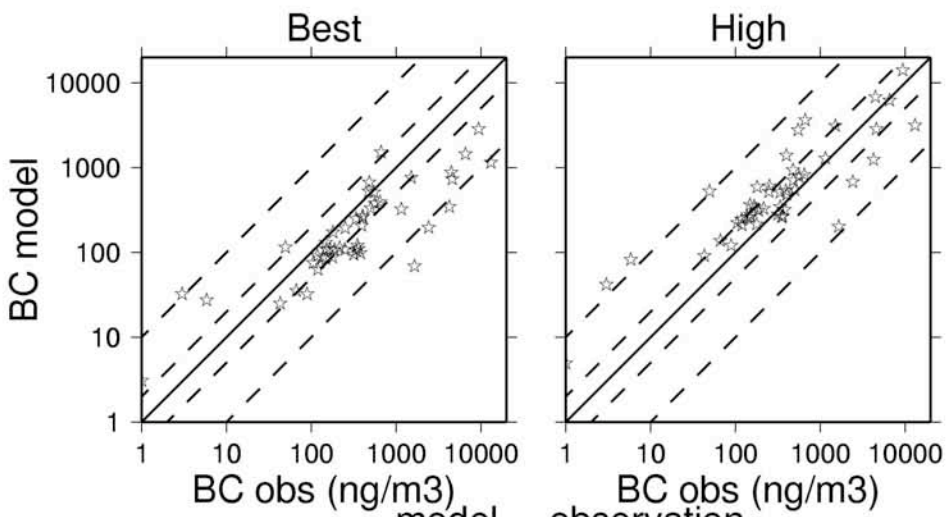
Emissions

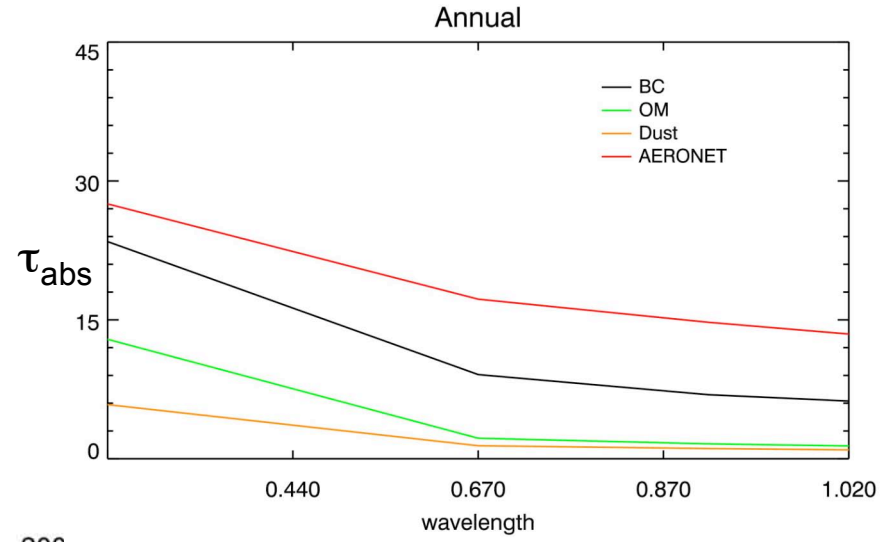
Carbonaceous aerosols:

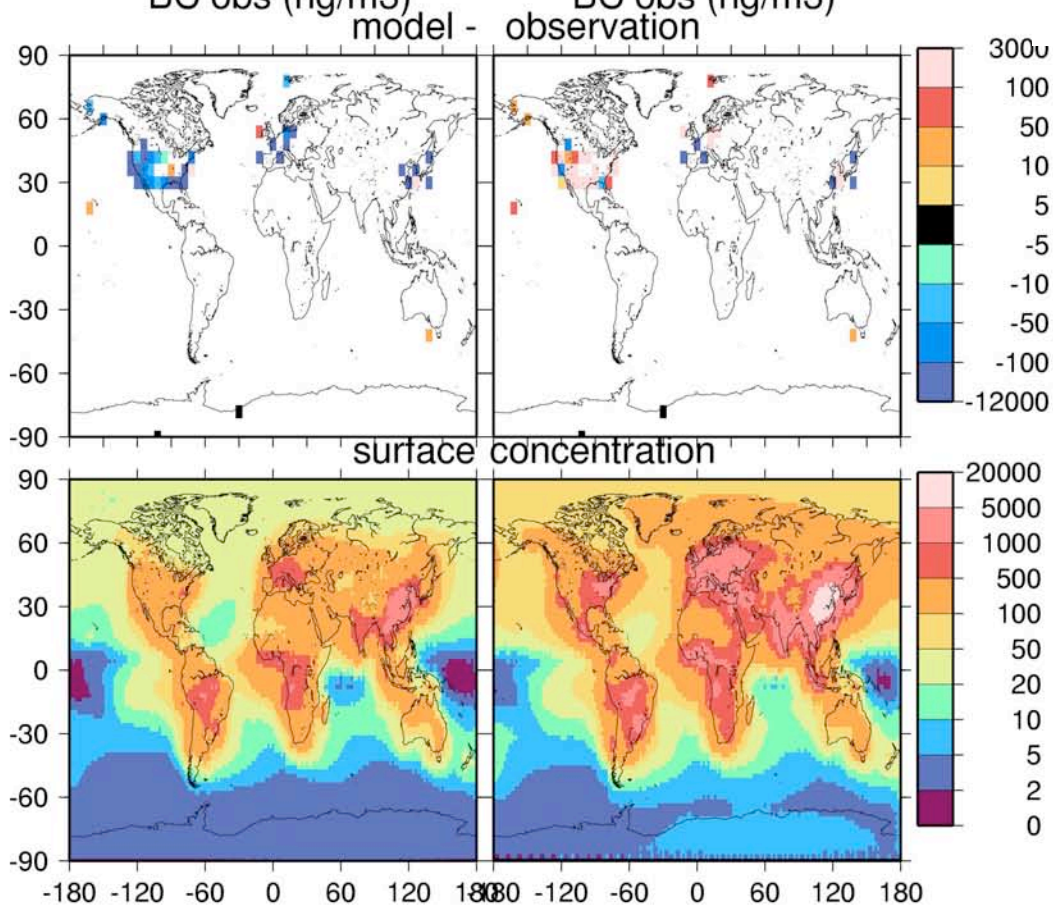
- Present-day industrial: Bond et al (2004)
- Future (IPCC SRES) industrial: Streets et al (2004)
- Biomass: VanderWerf et al.

SO_2 (gaseous precurser to sulfate):

- Present-day industrial: EDGAR 2.3
- Future: IPCC SRES
- Natural emissions (Koch et al., 2005)







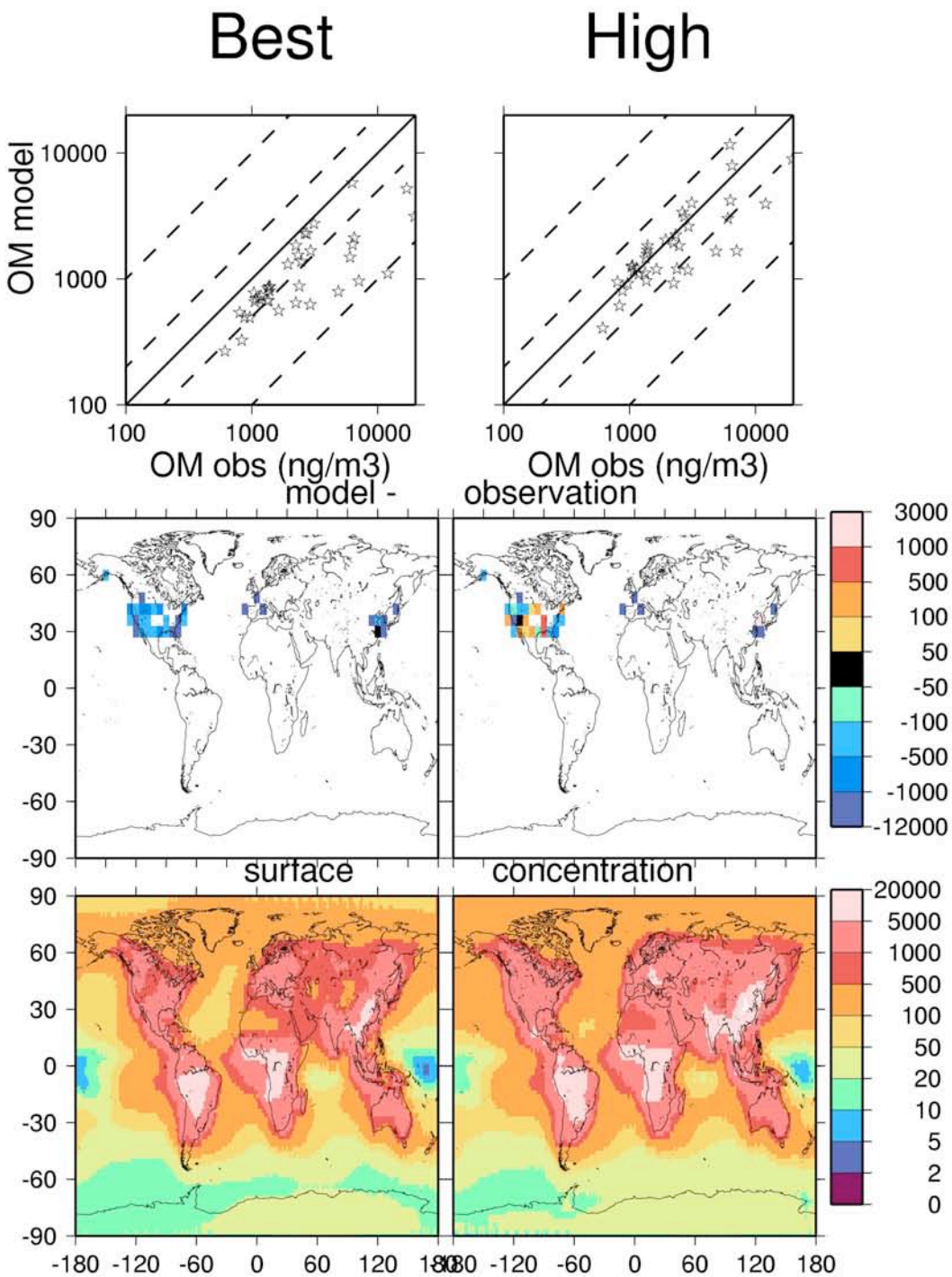
BC model performance

Model versus AERONET Tau-absorption (S. Zhang)

Model low by 13% (440 nm) to 50% (1020 nm)

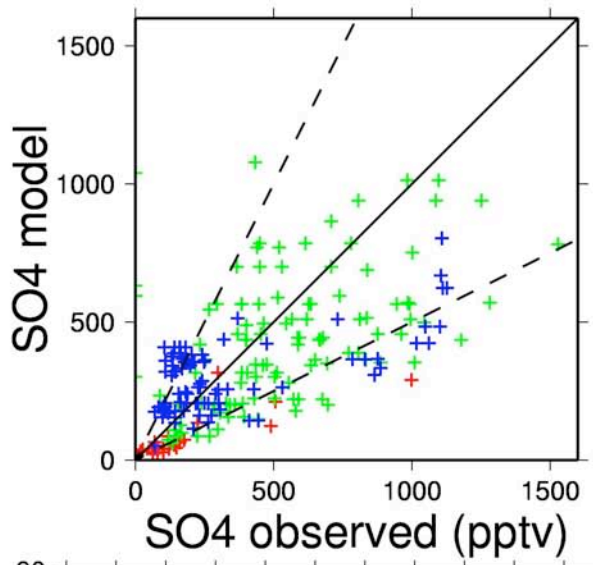
Model vs annual average surface concentration:

Model low by about factor of 2

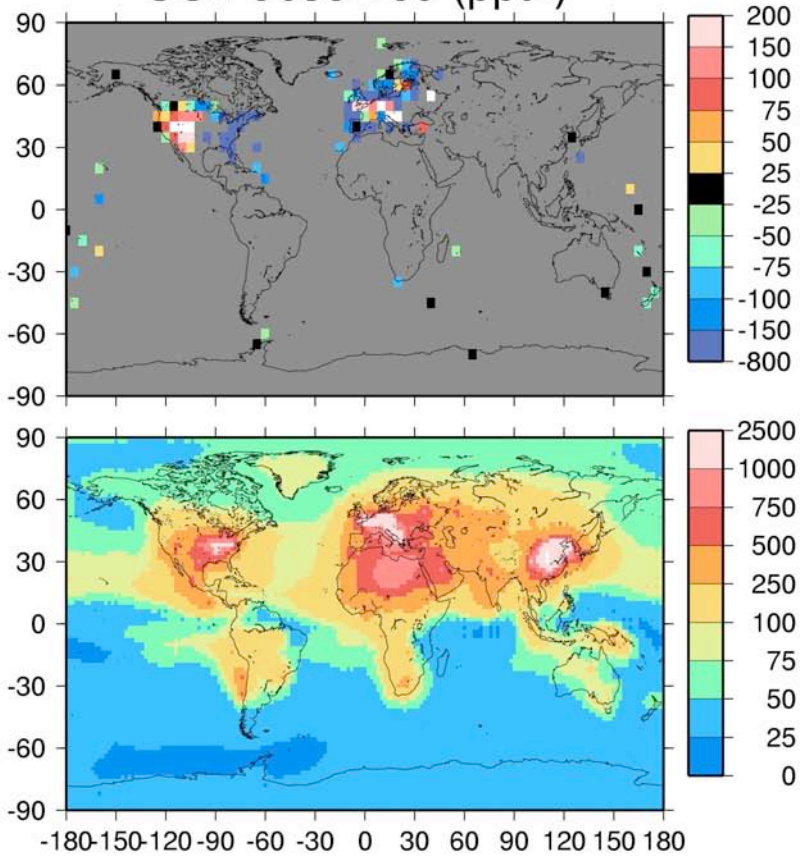


OC model performance

Model vs annual average surface concentration:
Model low by > factor of 2



Green: Europe (EMEP)
Blue: US (IMPROVE)
Red: Remote (Prospero)



Sulfate model performance

Model vs annual average surface concentration: Overall agreement within a factor of 2.

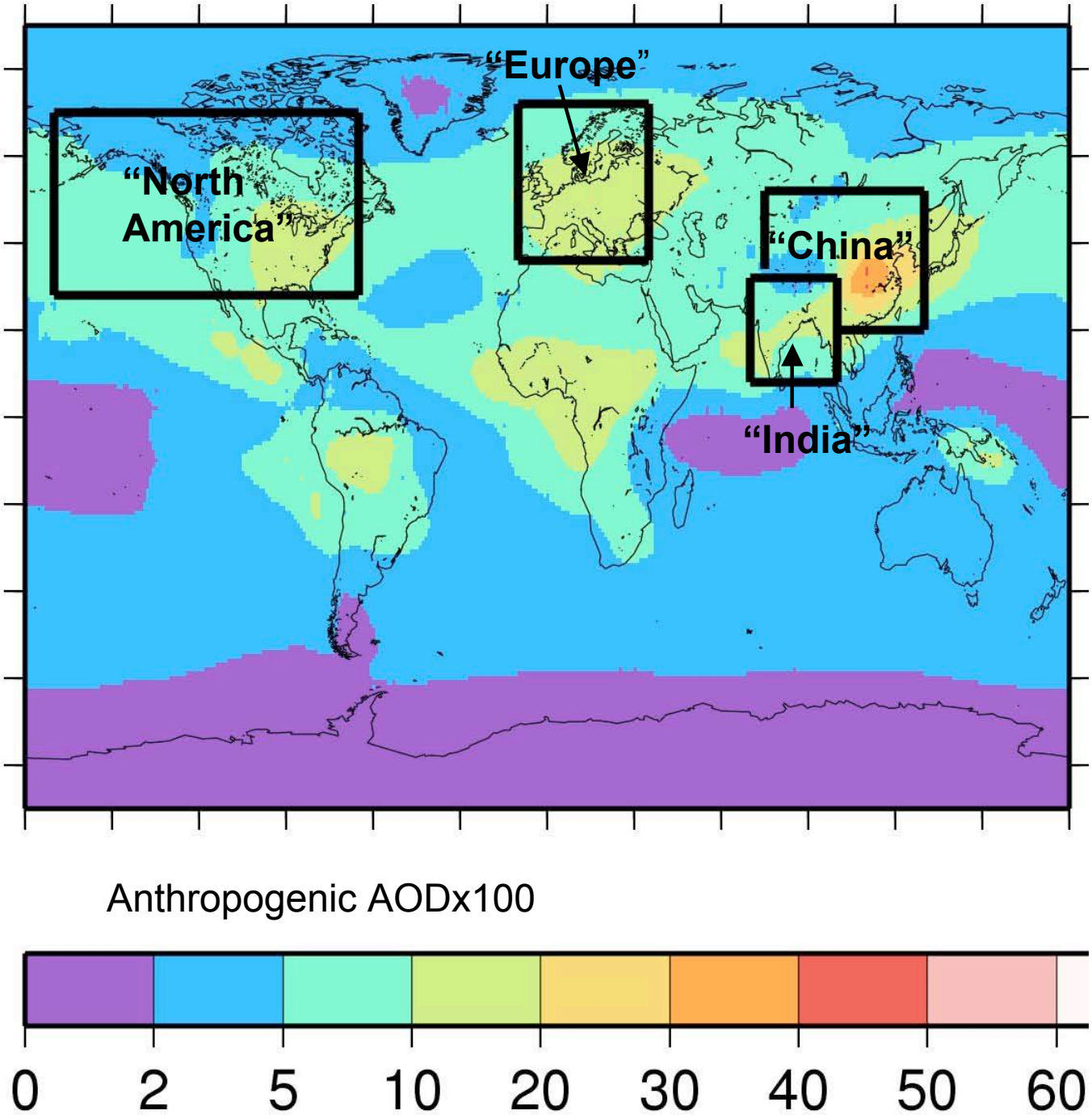
Sectoral Experiments

Eliminate aerosols from each of the following sectors:

1. Residential
2. Industrial
3. Power
4. Transport
5. Biomass
6. (Natural)

Regional Experiments

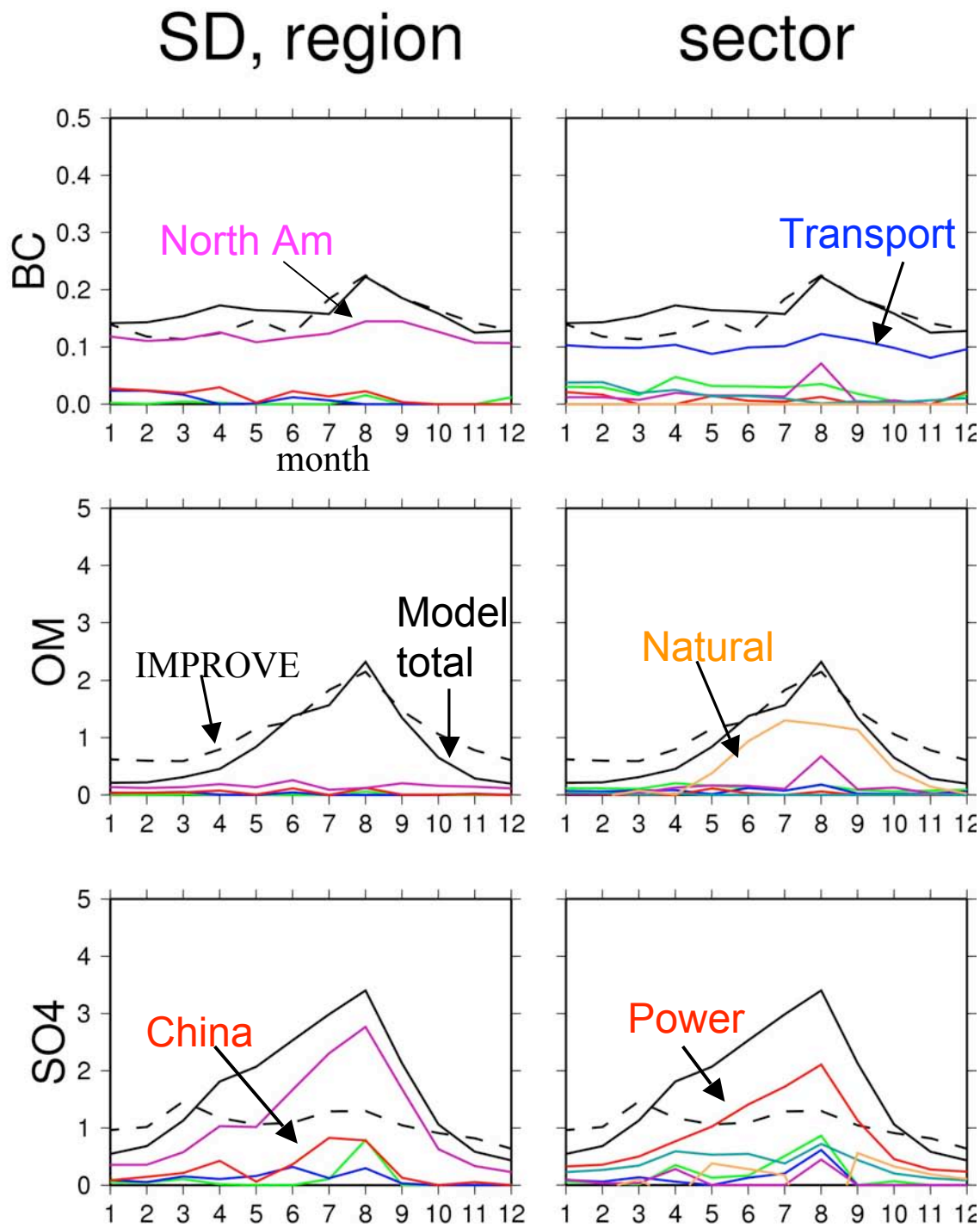
- We consider contributions (from industrial emissions only) from these regions
- Labels are *approximate*



Rocky Mtns, US
(high altitude)

Regions
- N America
- Europe
- China
- India

Sectors
- Transport
- Natural
- Residential
- Power
- Biomass
- Industry



Hawaii, Mauna Loa (3400 m)

Regions

- N America
- Europe
- China
- India

Sectors

- Transport
- Natural
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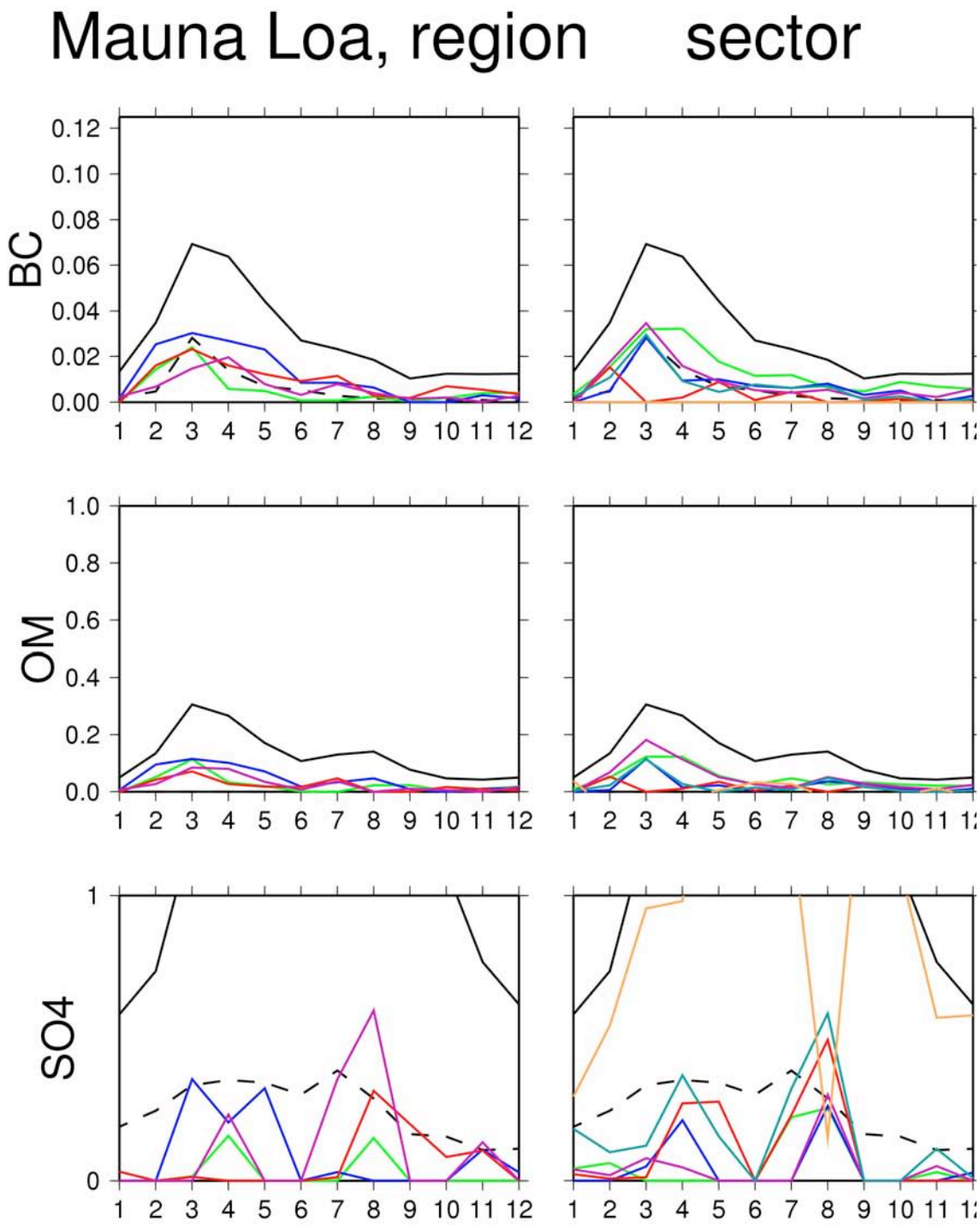
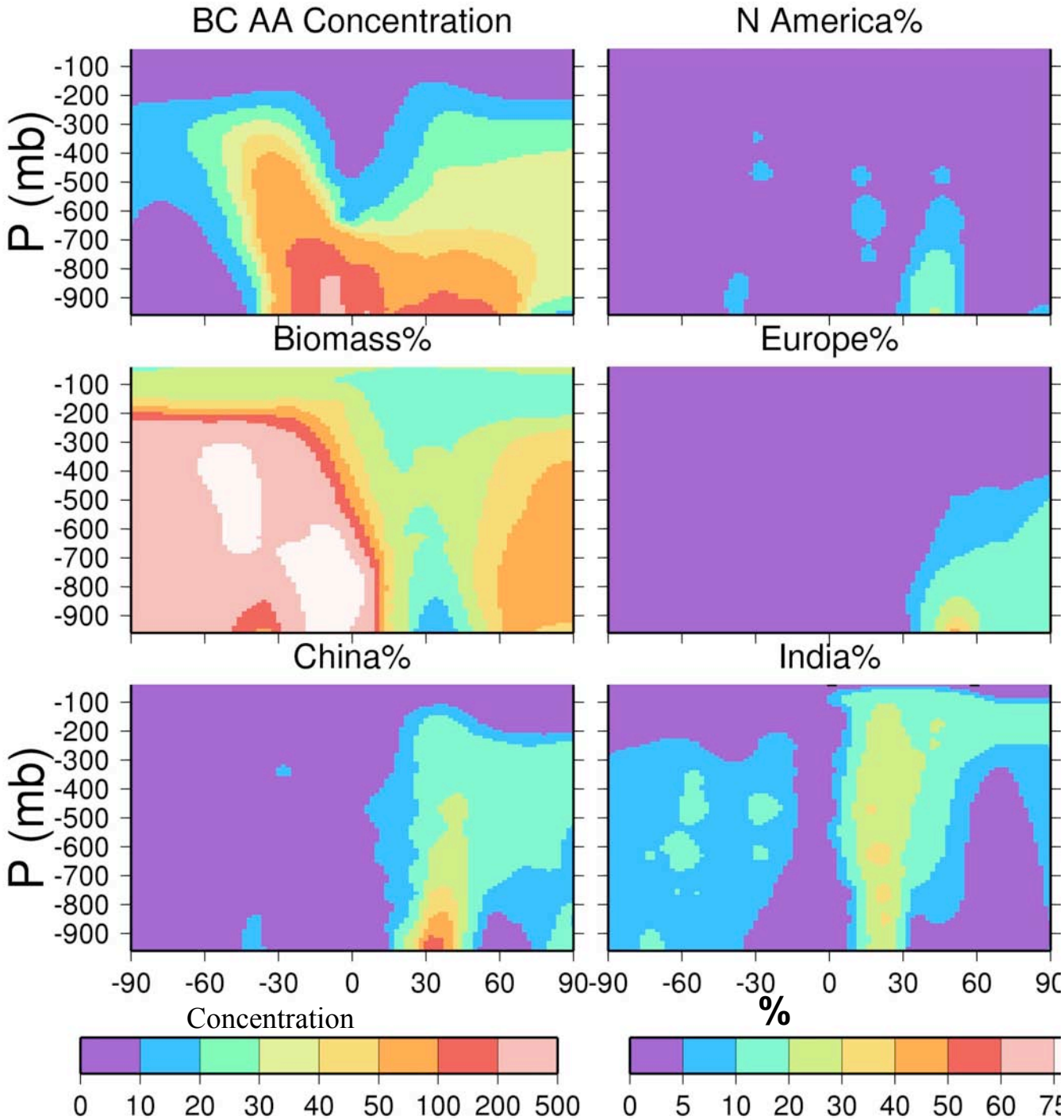


Latitude-altitude view: black carbon concentration percent from each region

- Aerosols from China and India tend to loft to high altitudes



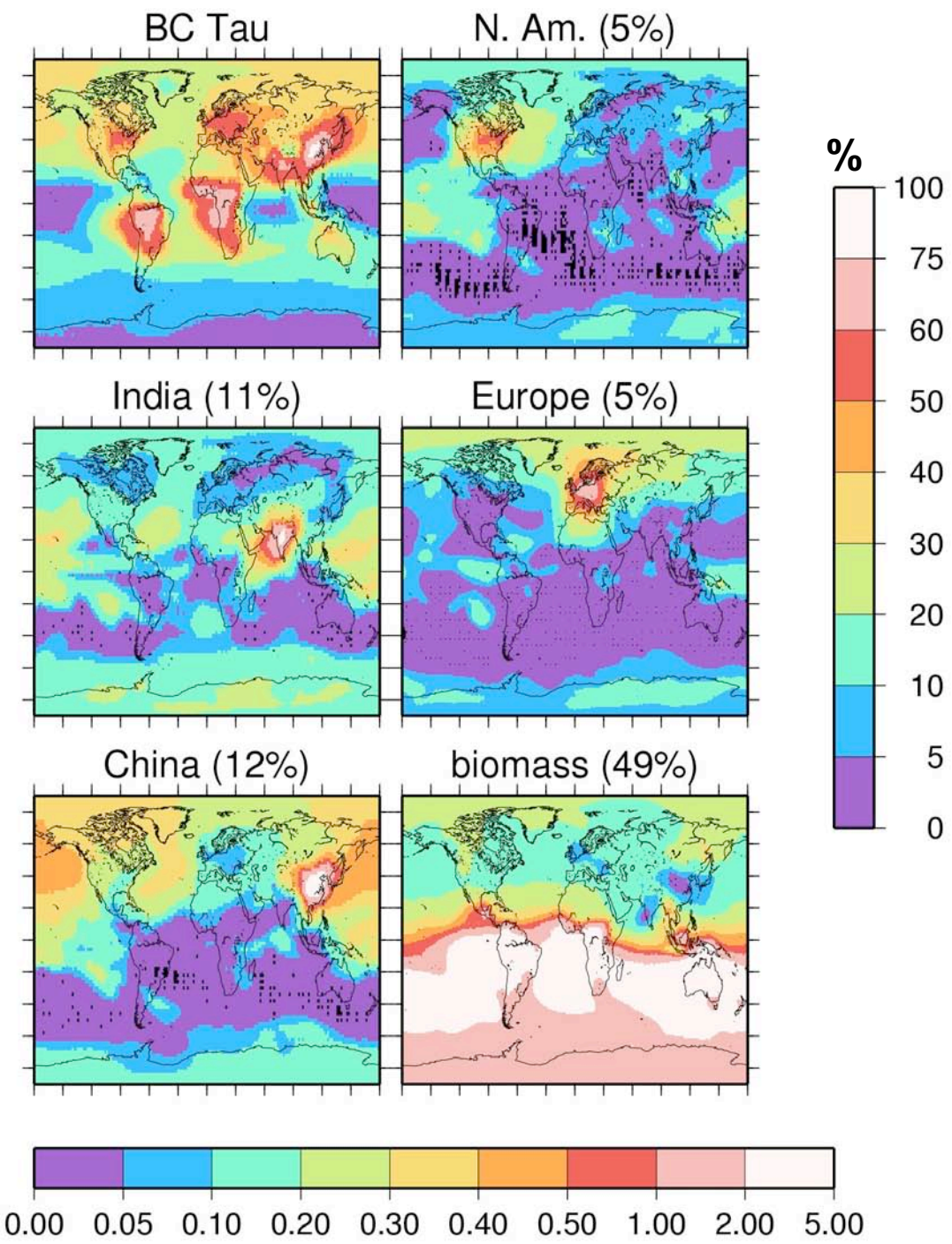
Column view: black carbon Optical thickness

China: exports to N. Pacific, N. Atlantic, Arctic

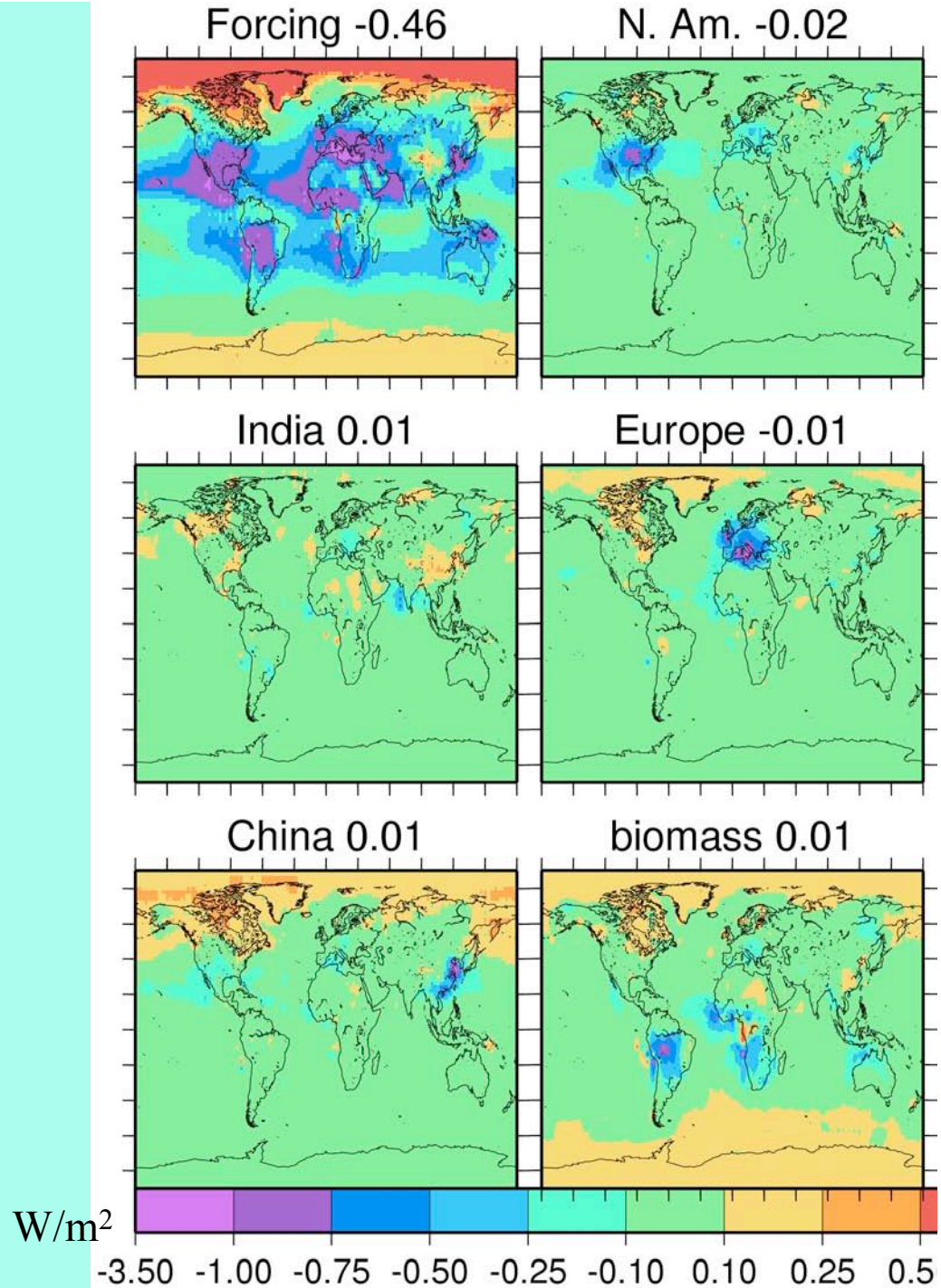
India exports to central Pacific

Europe exports to Arctic

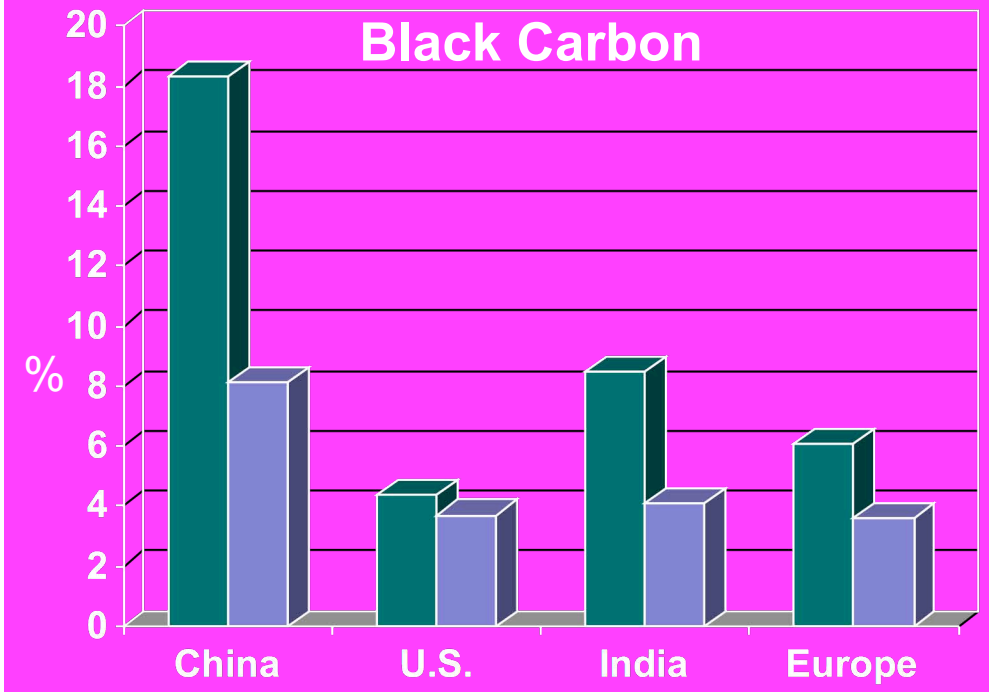
U.S. exports to central Pacific



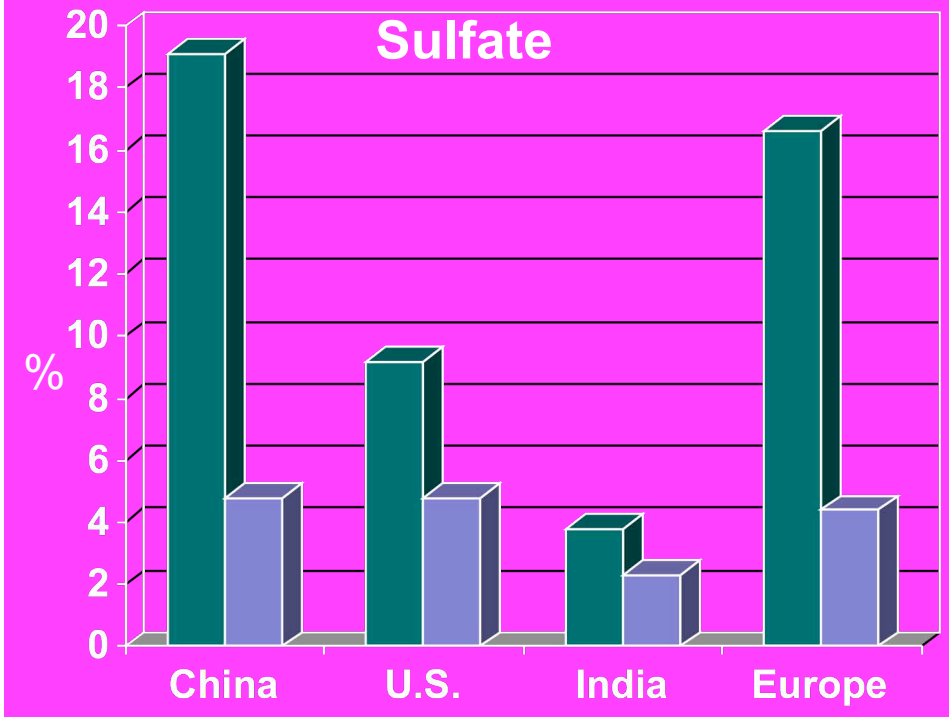
Forcing (TOA instantaneous) due to regional emissions



Emission and Regional Burden

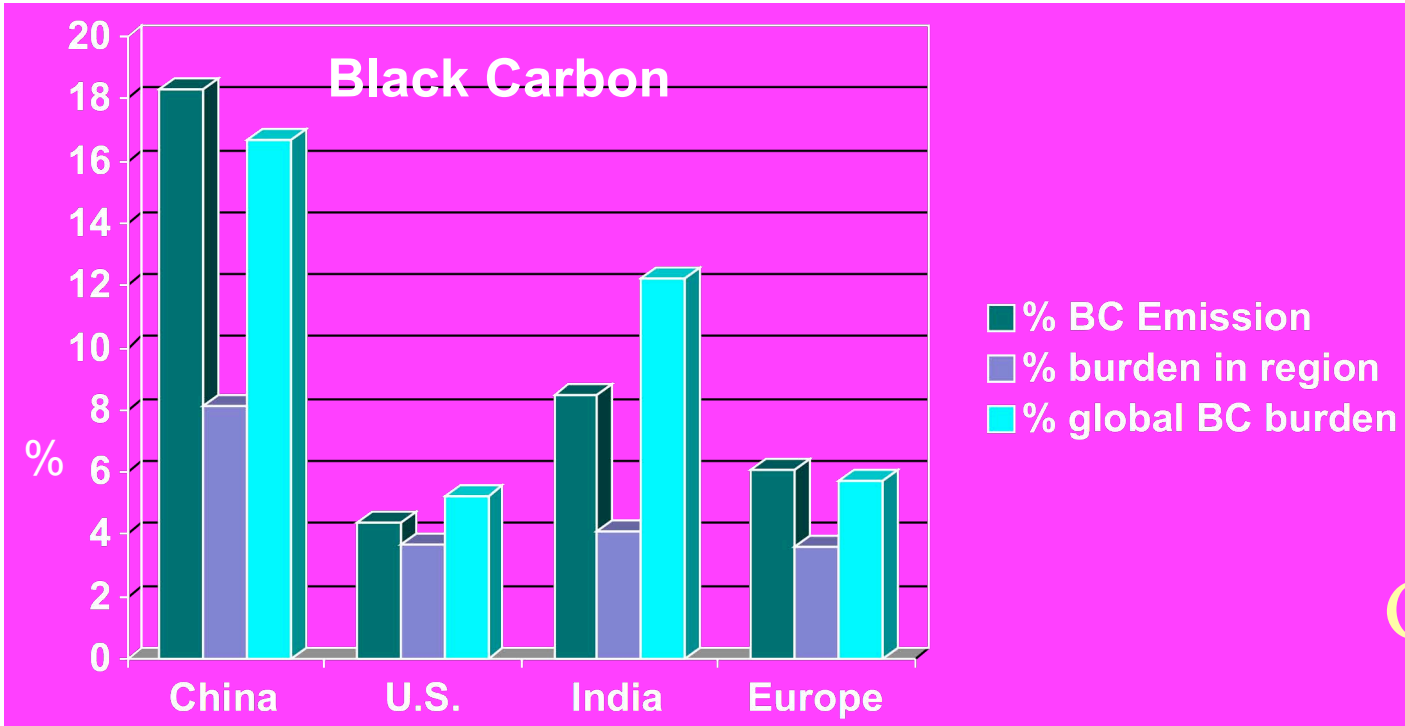


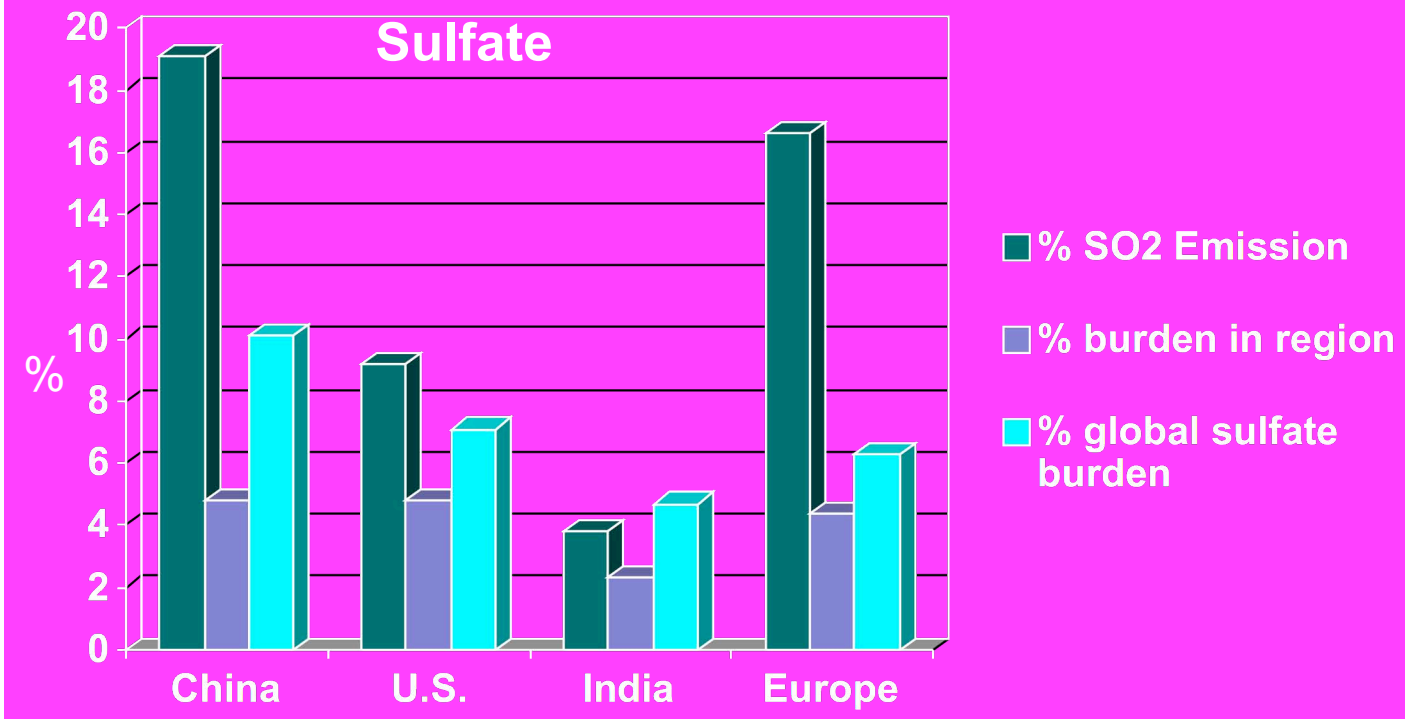
China and India export much of their BC



China, Europe and the U.S. export much of their sulfate

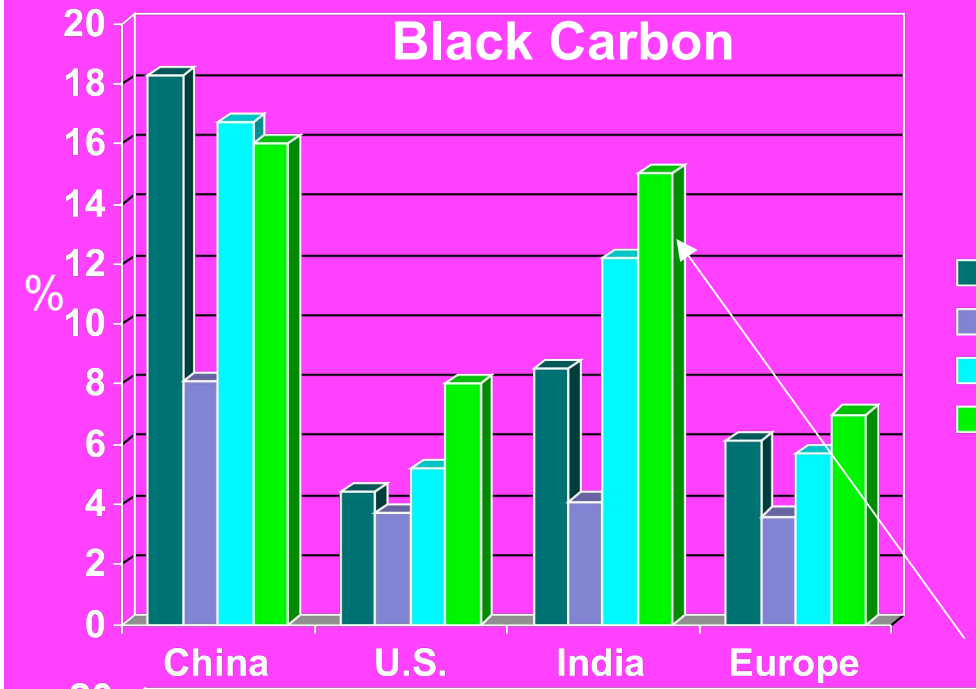
Emission, Regional Burden and Global Burden



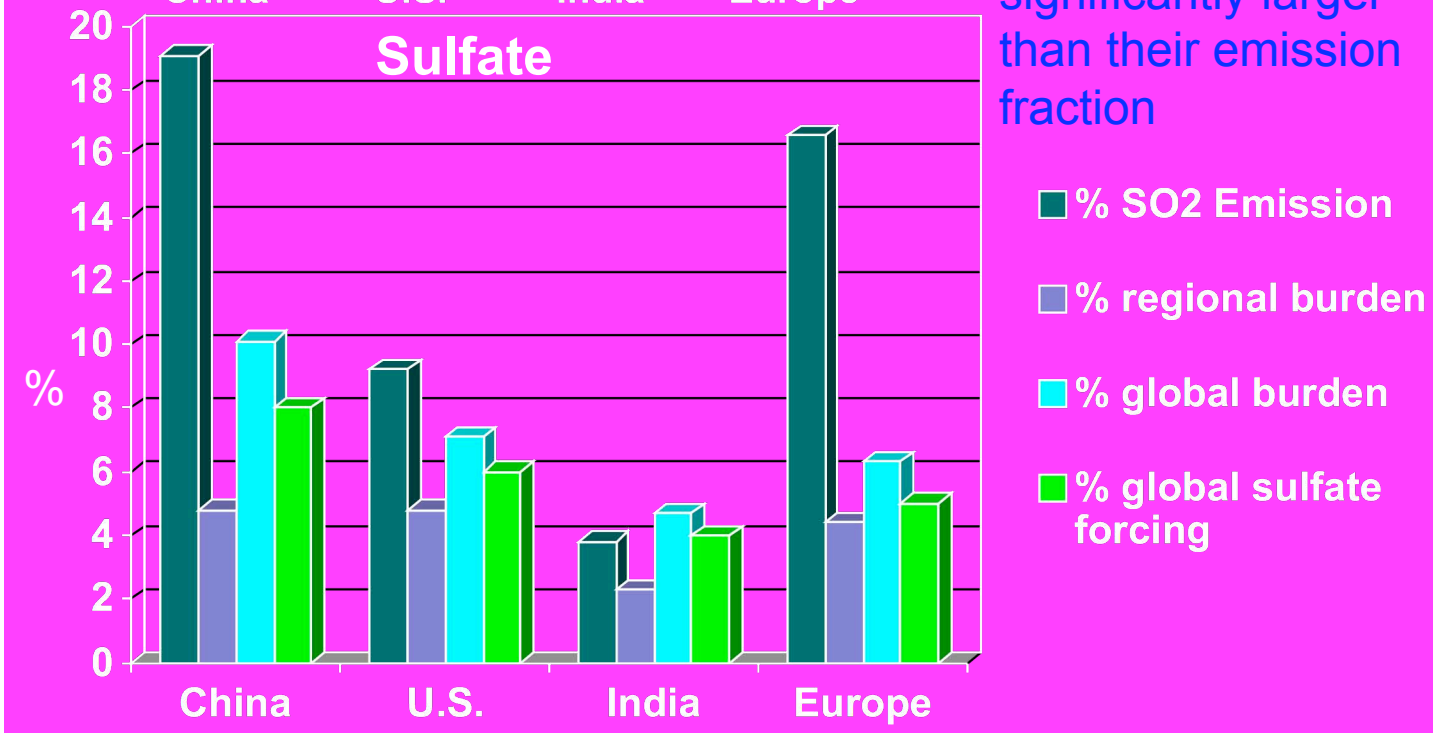


Much of the SO_2 emitted in Europe and China is dry deposited. Presumably this is related to *oxidation limitation* in these regions.

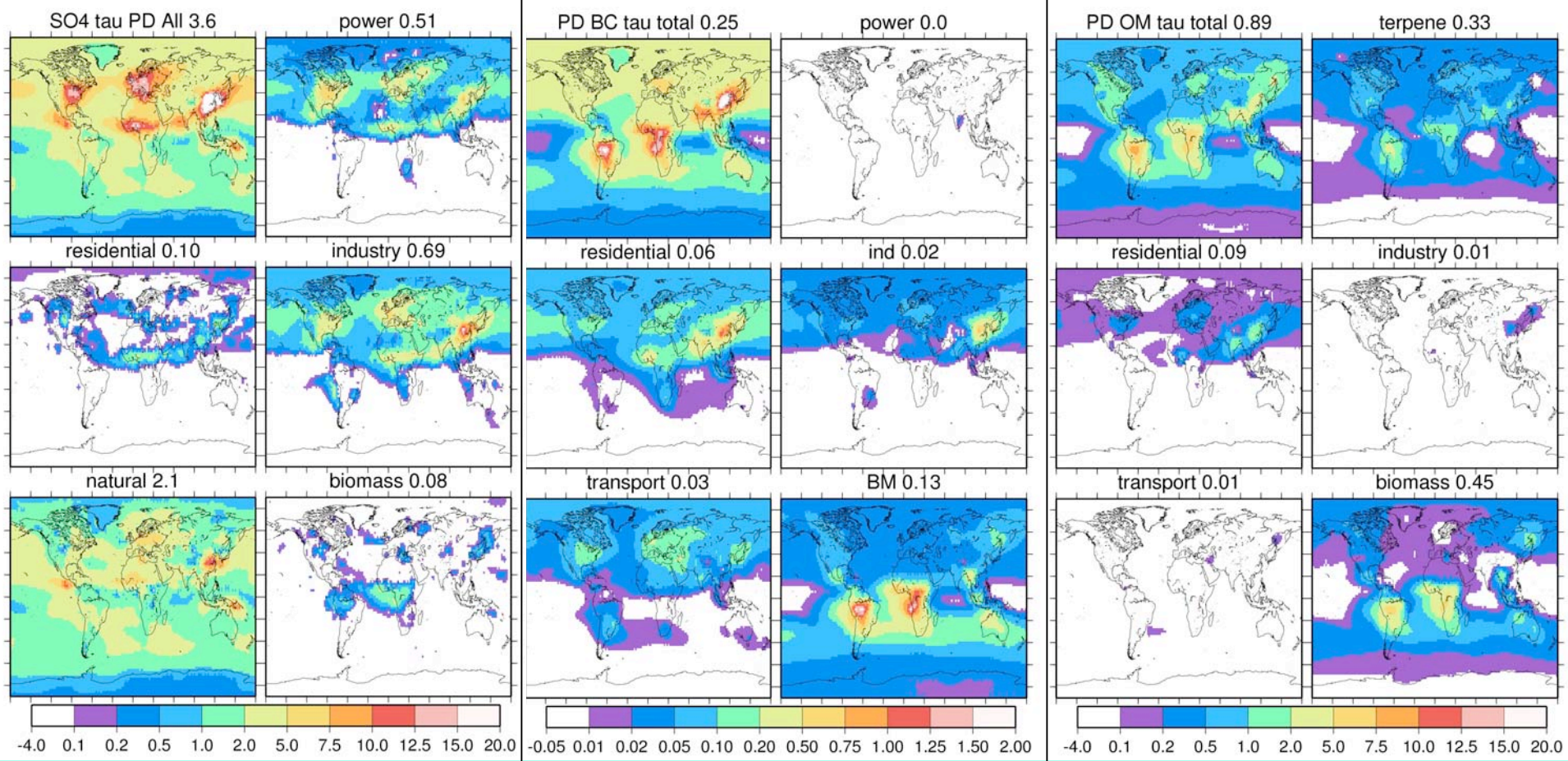
Emissions, Regional and Global Burdens and Radiative Forcing



BC forcing from US and India are significantly larger than their emission fraction



Optical thickness from each sector (by species)

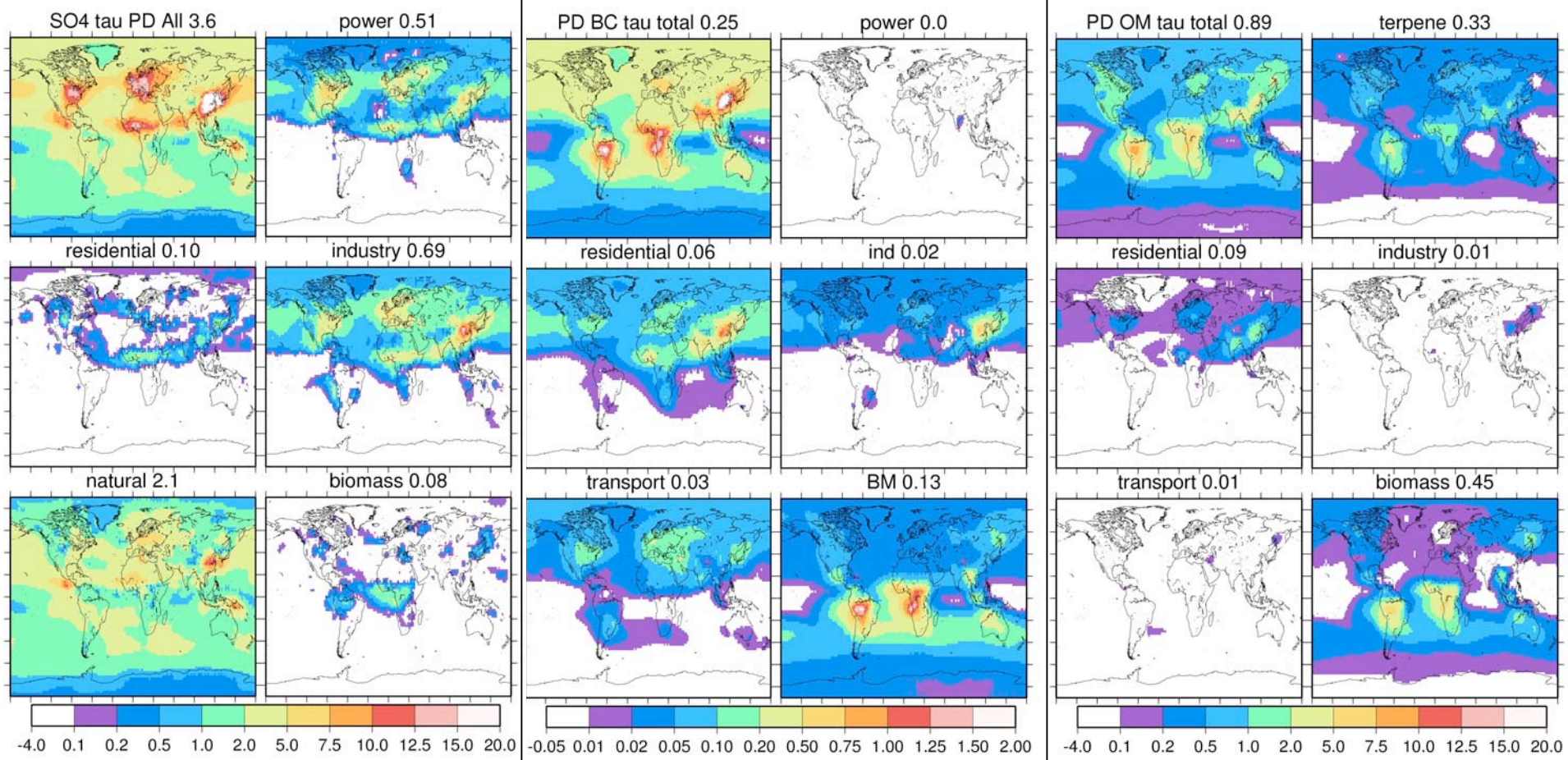


Sulfate is mostly from
Industrial
Power
(natural)

Black Carbon is from
Transport
Residential
Biomass

Organic Carbon from
Biomass
Natural
Residential

Optical thickness from each sector (by species)



Sulfate is mostly from
- **Industrial**
- **Power**
- **(natural)**

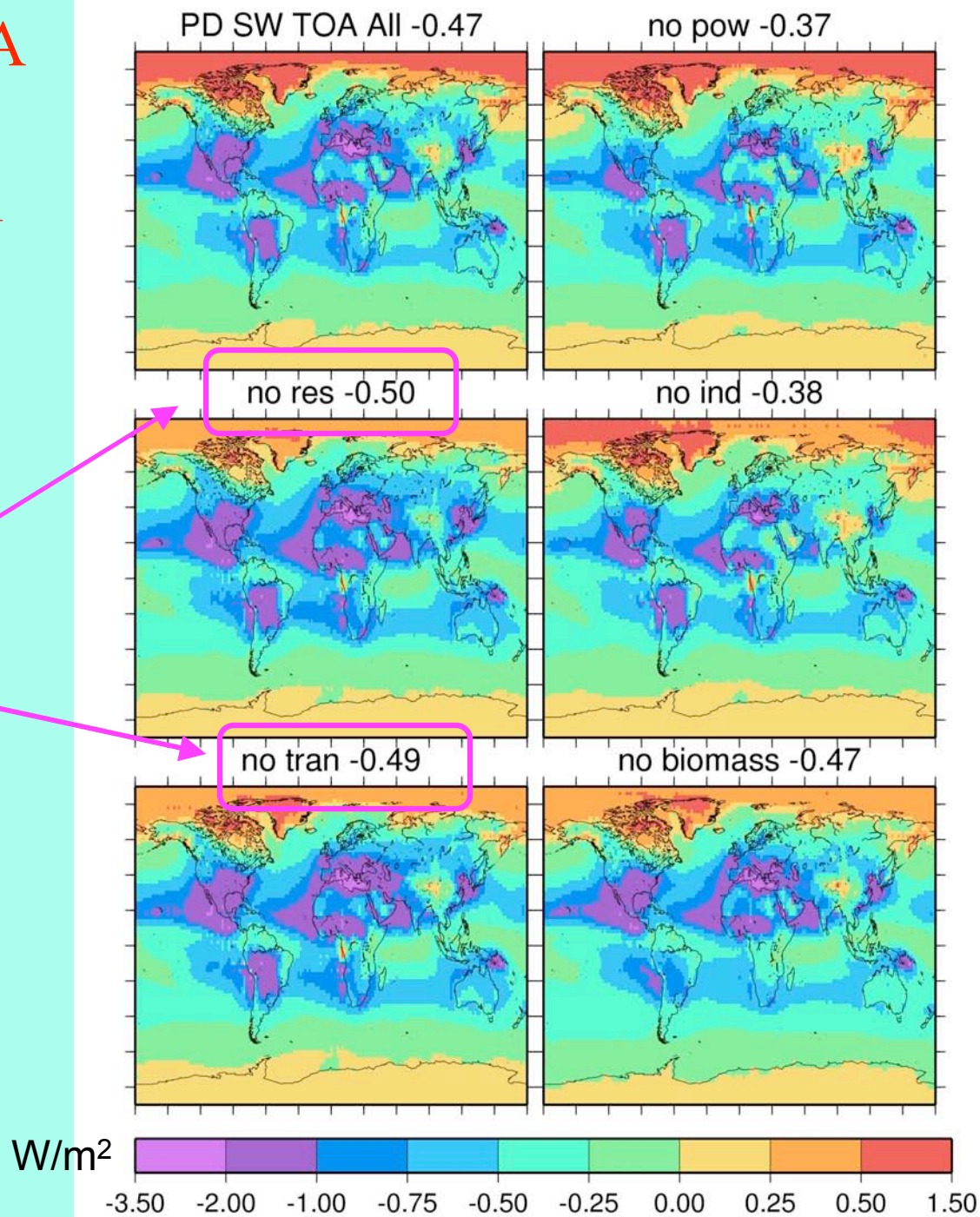
Black Carbon is from
- **Transport**
- **Residential**
- **Biomass**

Global warming targets?

Organic Carbon from
- **Biomass**
- **Natural**
- **Residential**

Total instantaneous TOA direct radiative forcing from sector elimination experiments

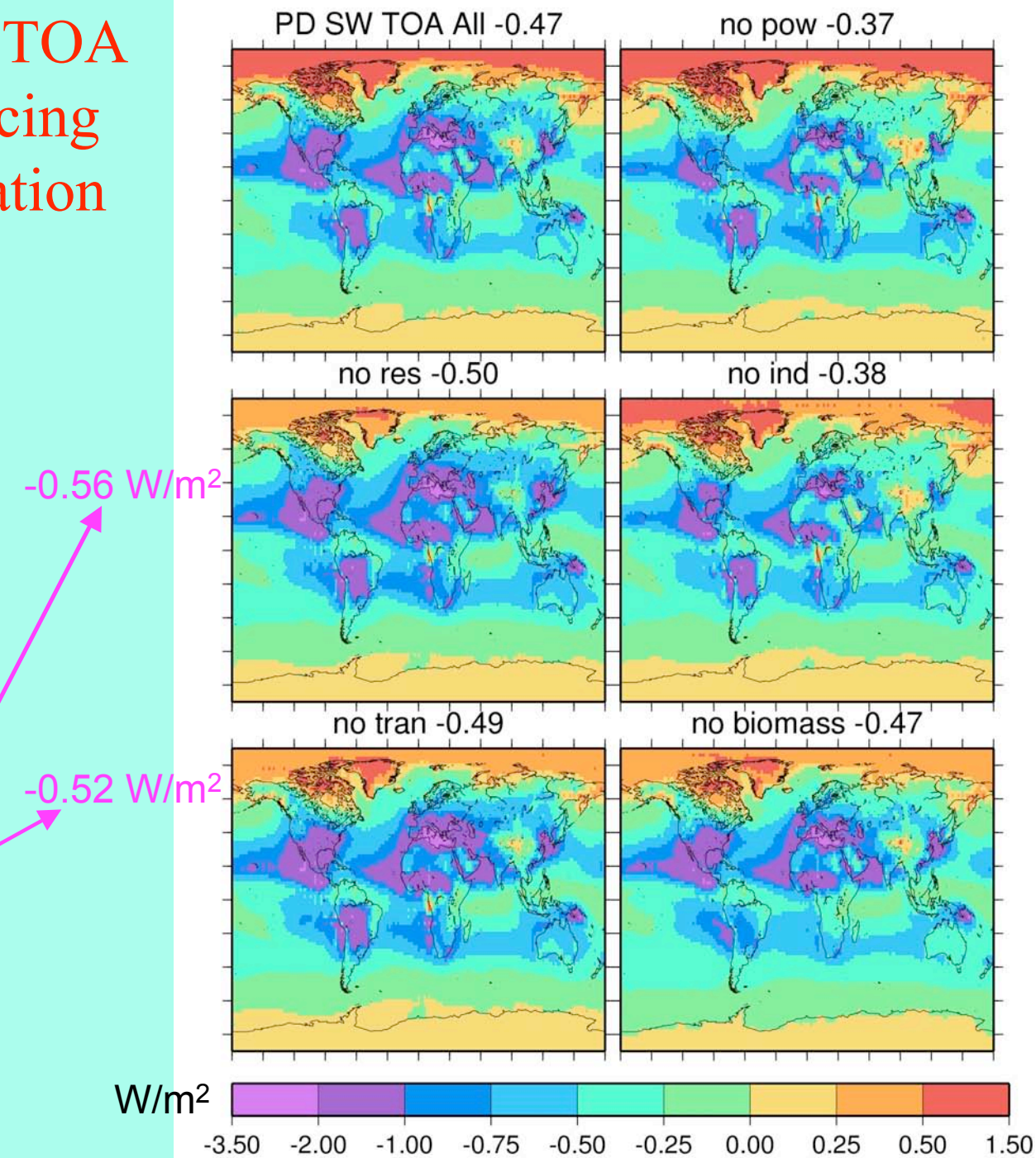
- Elimination of residential or transport emissions would result in modest increase in net negative forcing.



Total instantaneous TOA direct radiative forcing from sector elimination experiments

- To what extent can we target subsectors (e.g. diesel, coal) and eliminate more BC than SO_2?

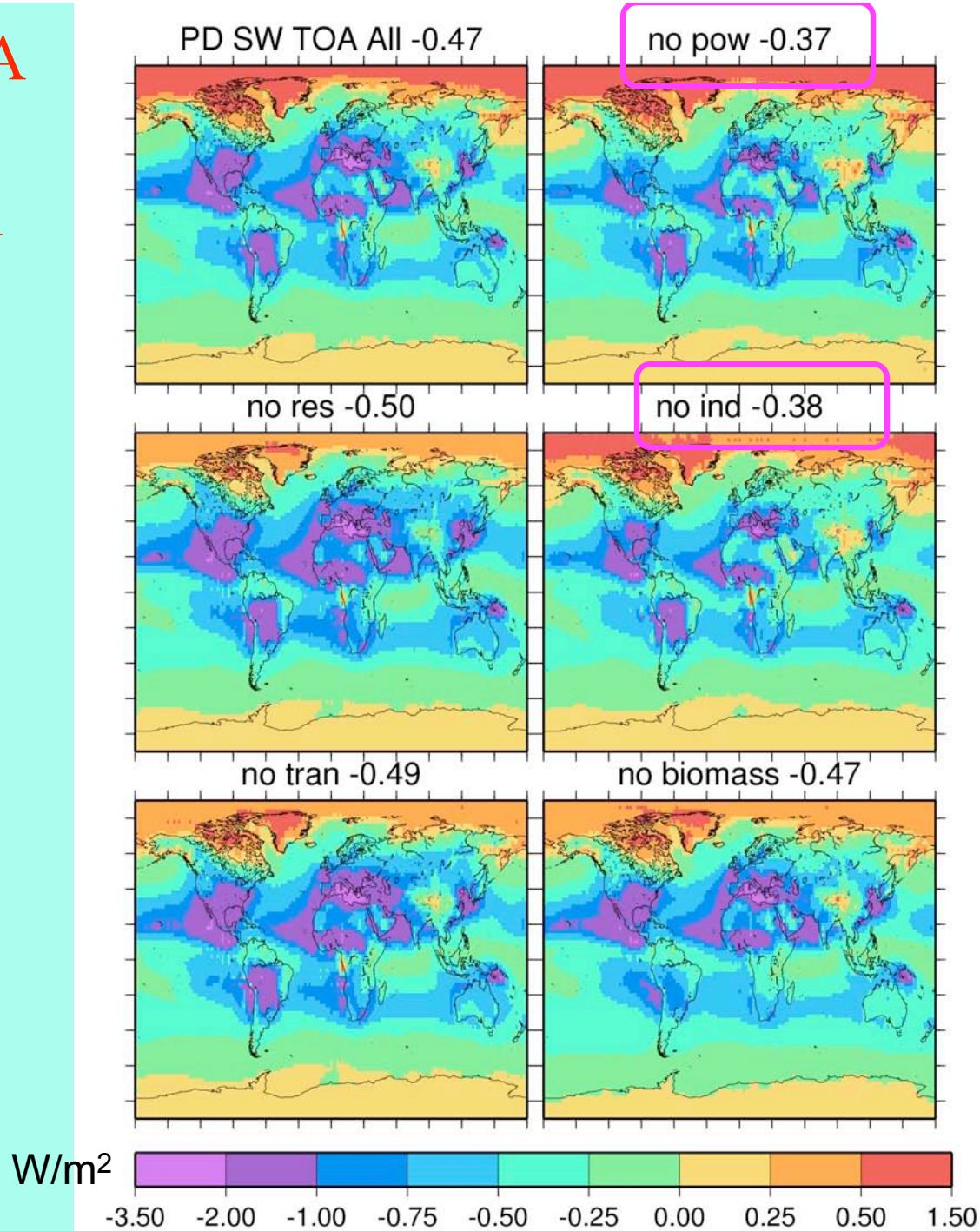
- If we could get rid of BC only we would get



Total instantaneous TOA direct radiative forcing from sector elimination experiments

- Elimination of residential or transport emissions would result in modest increase in net negative forcing.

- Elimination of industry or power emissions results in substantial decrease in negative forcing



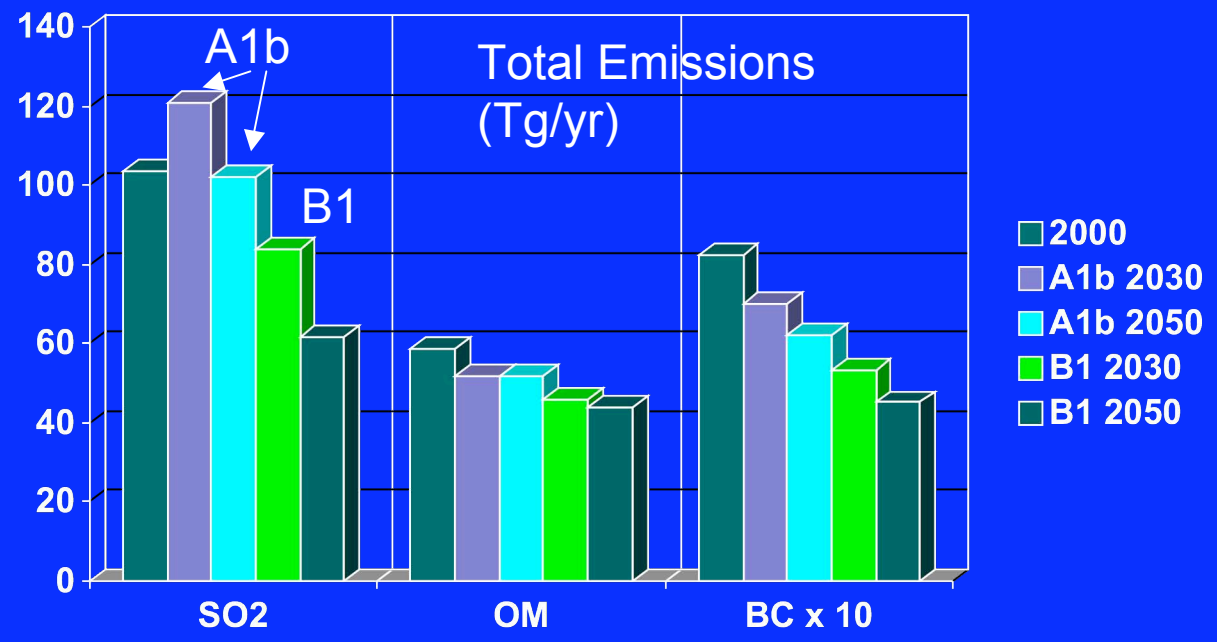
Two future SRES scenarios for 2030 and 2050

- A1b: Rapid economic growth, low population growth, globalization, privatization, new and efficient technologies. Economically driven technology development.

- B1: Rapid economic growth, low population growth, globalization, change to service and information economy, emphasis on global solutions to social and environmental problems. Introduction of clean and efficient technologies.

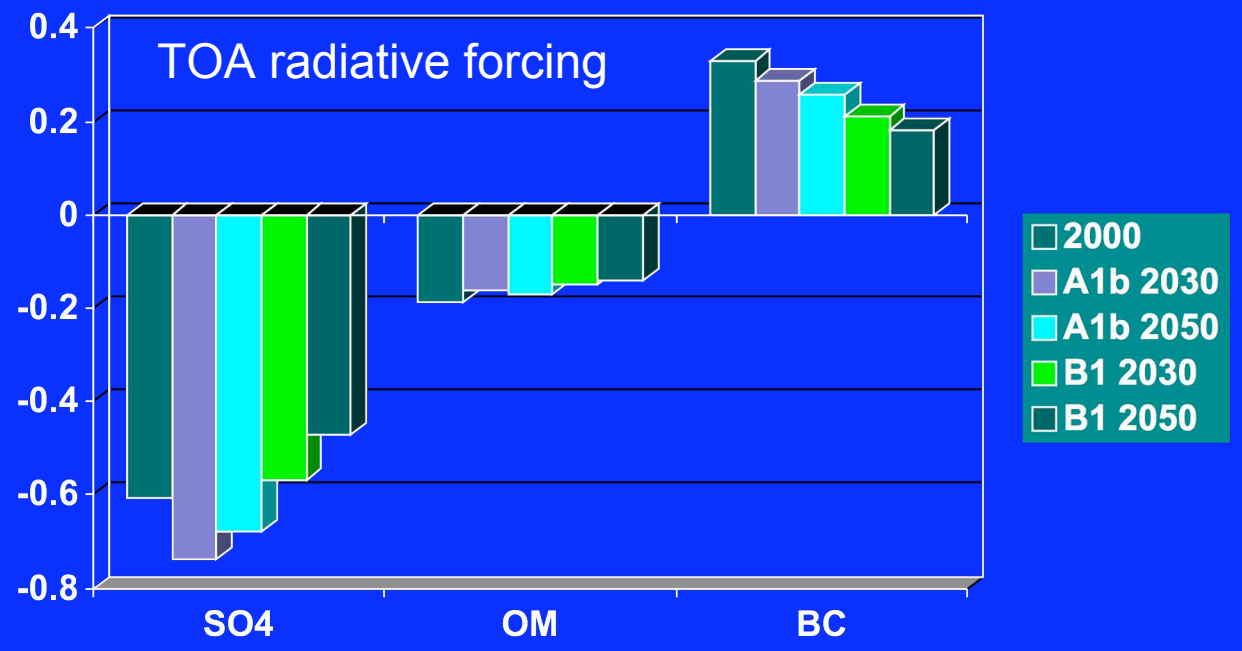
- Emissions were gridded for each species (Streets et al., 2004)

SRES emissions and calculated TOA radiative forcings

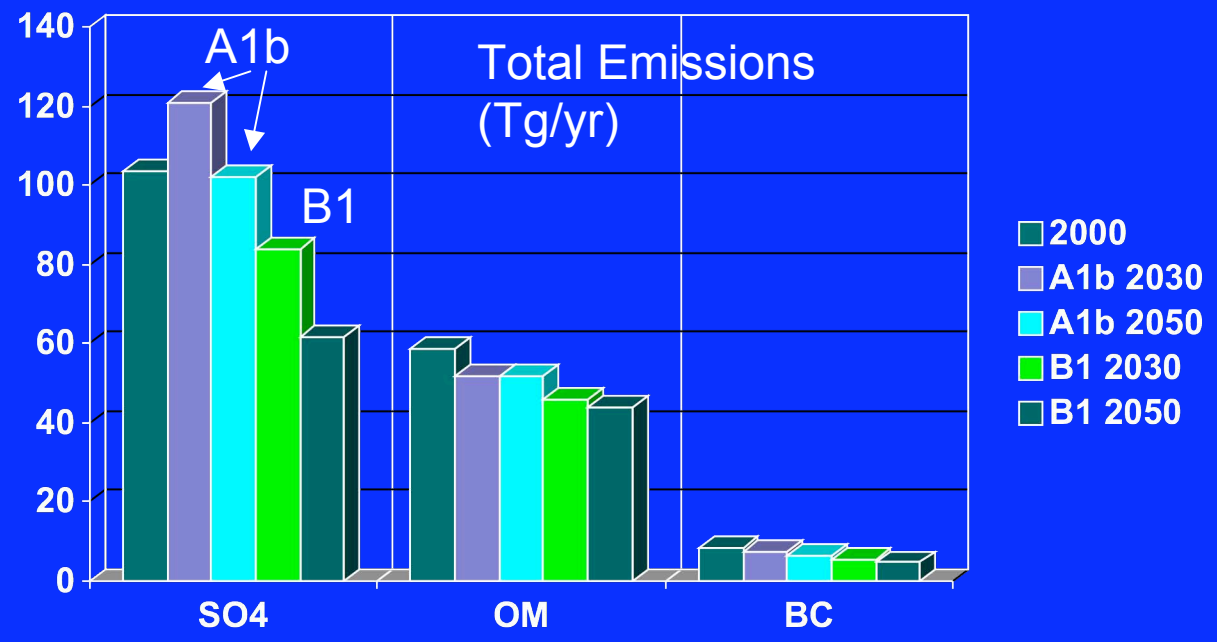


Is the change in forcing proportional to the change in emissions?

$F_f = F_{PD} \times E_f/E_{PD}$



SRES emissions and calculated TOA radiative forcings



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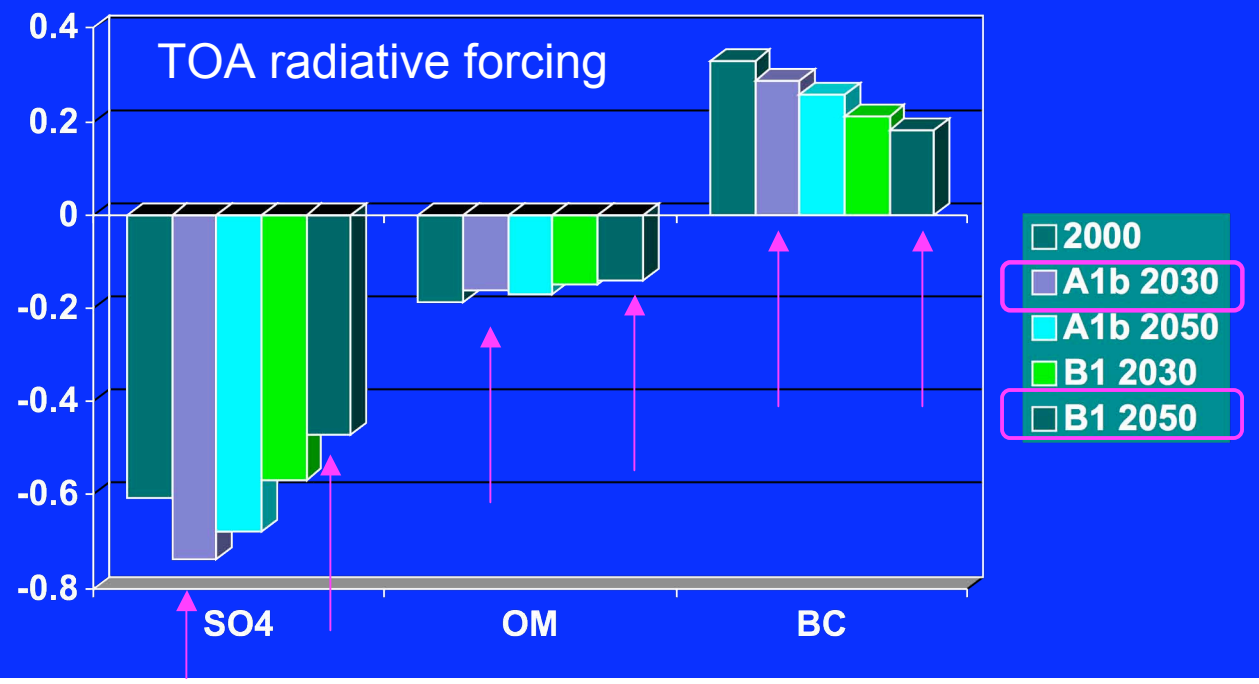

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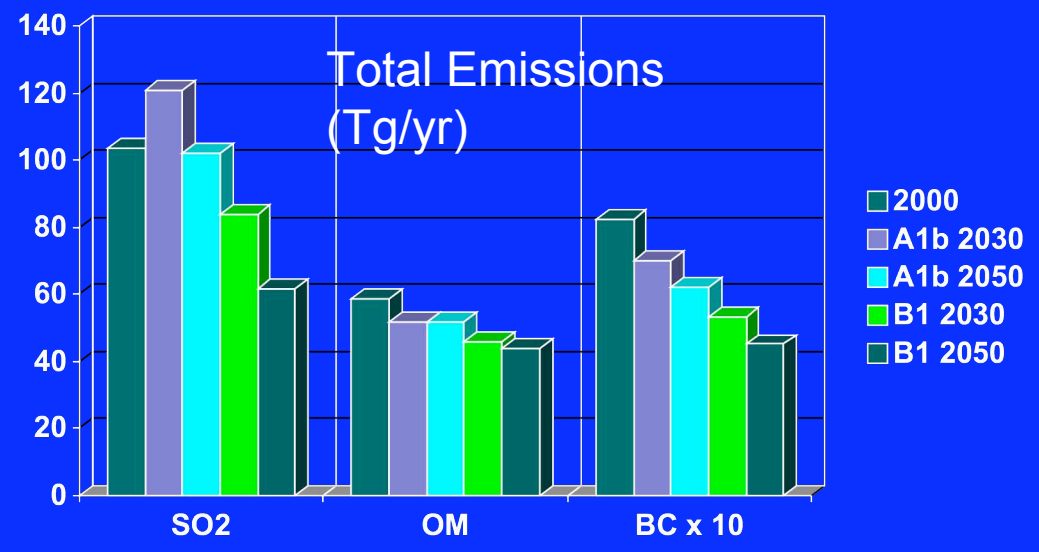
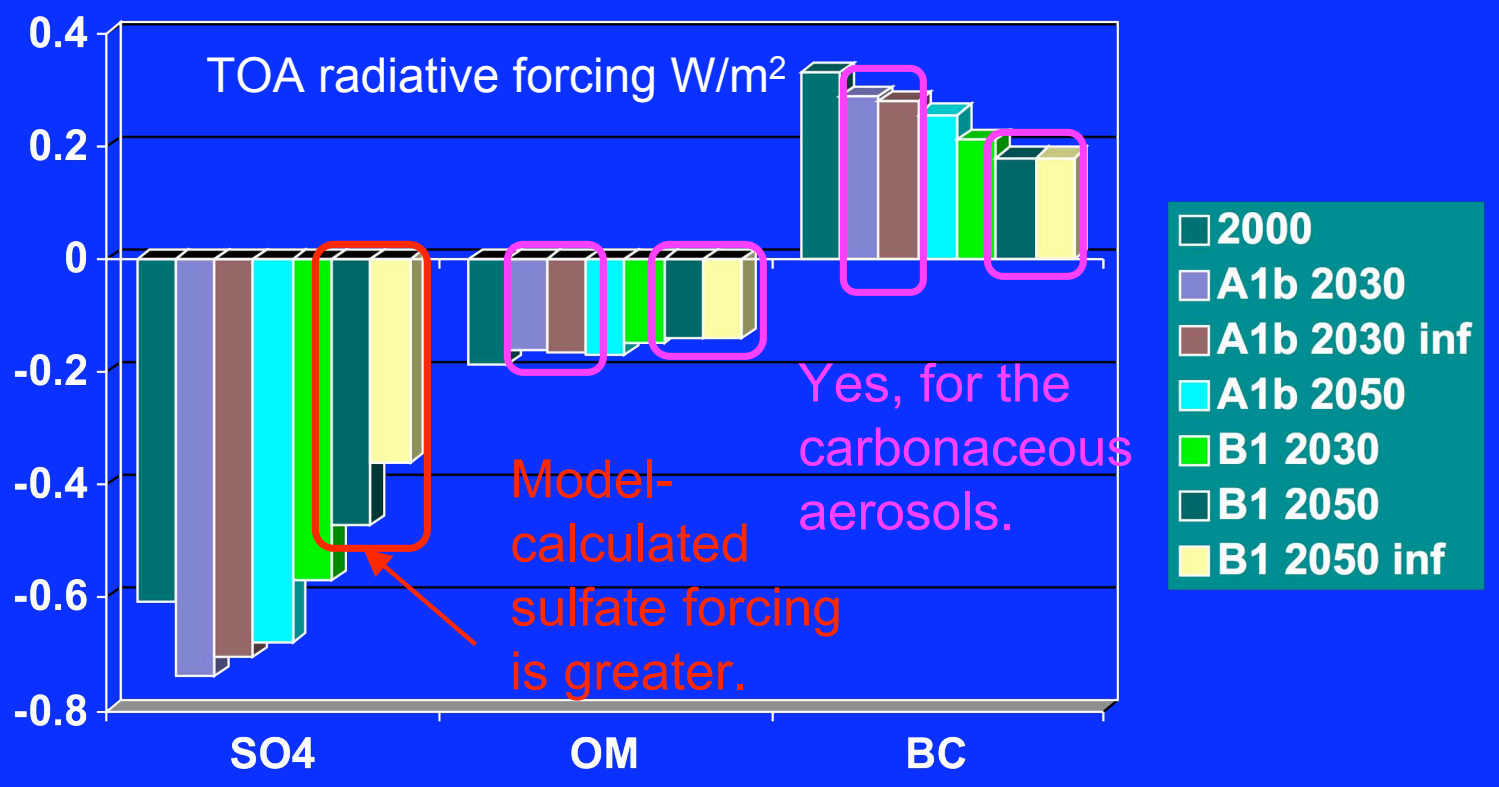
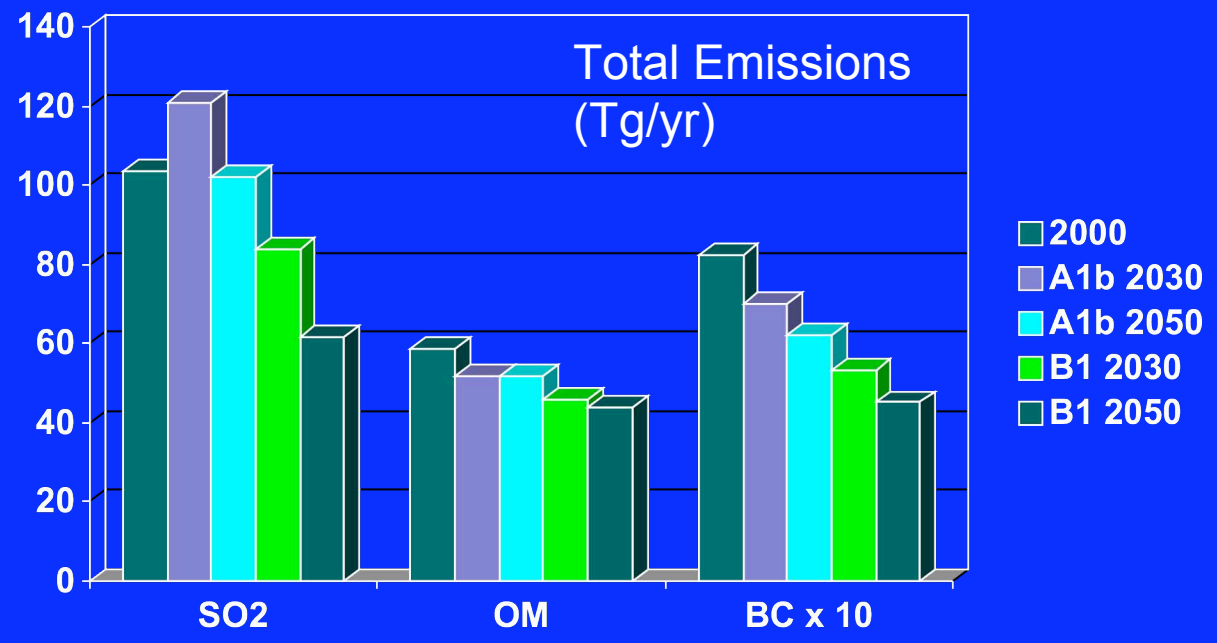
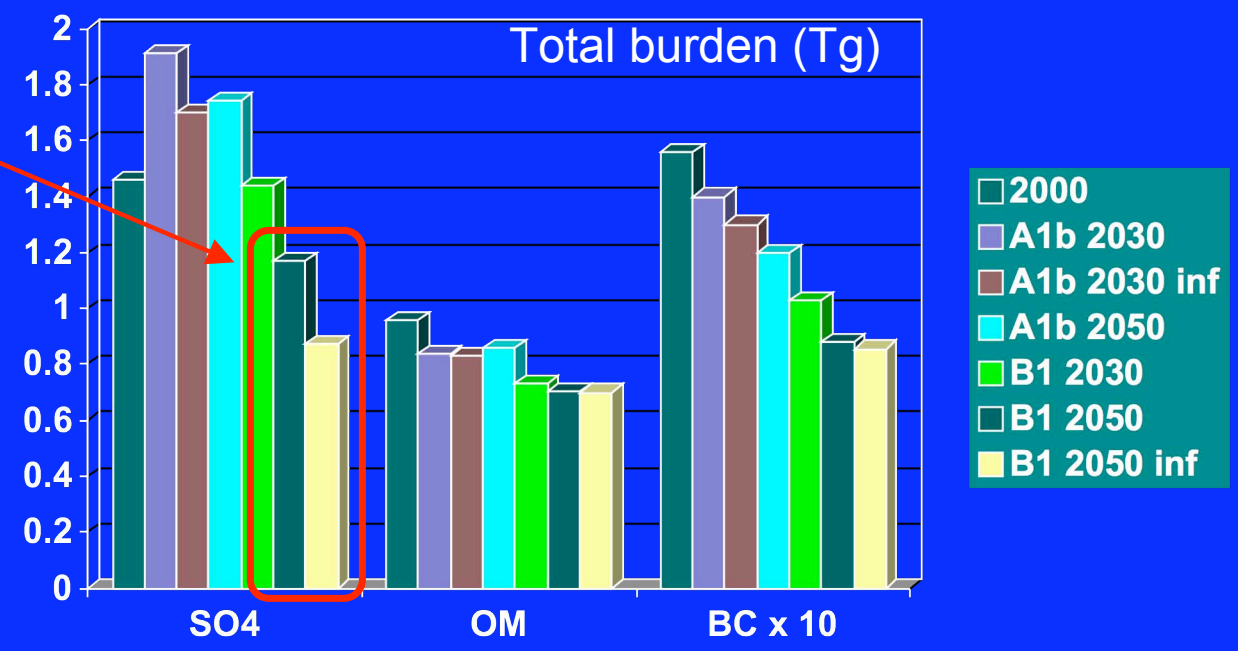




This is because the future model-calculated sulfate **burden** is more than proportional to the future emissions

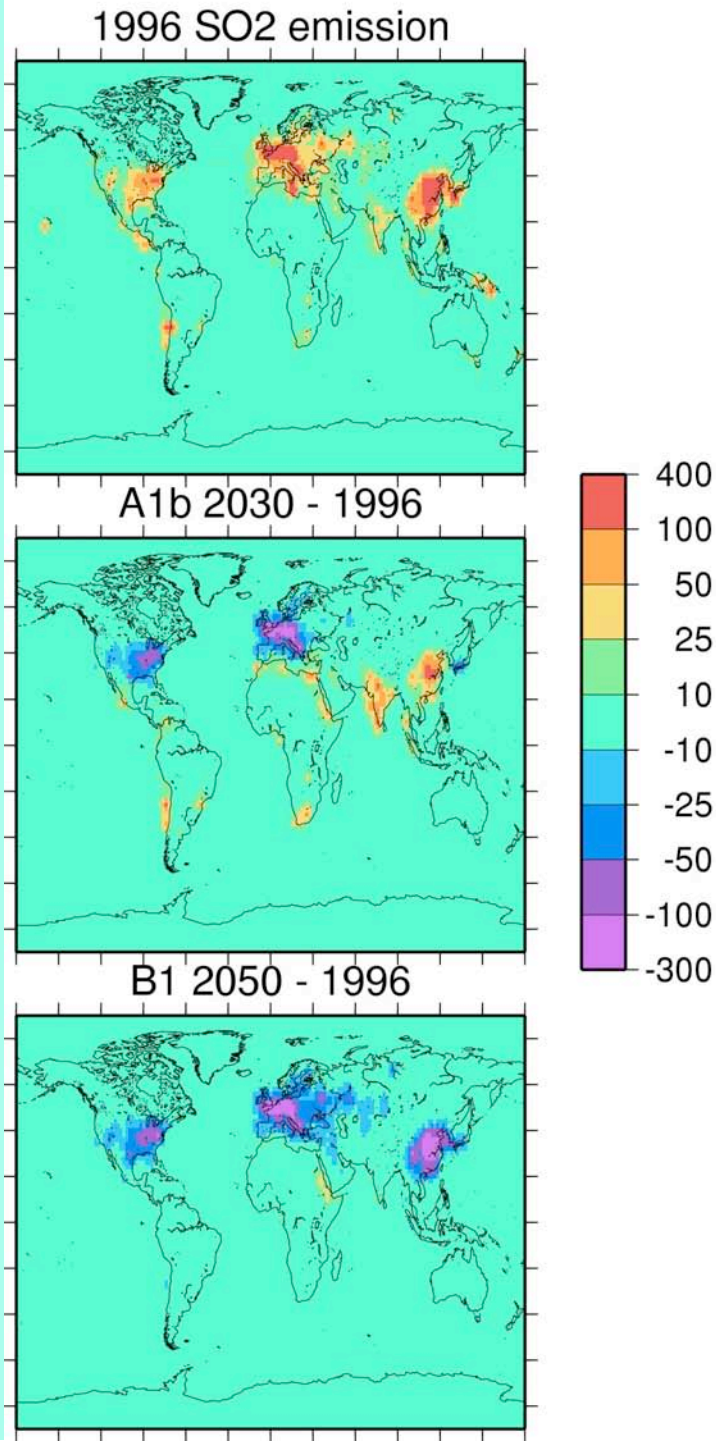




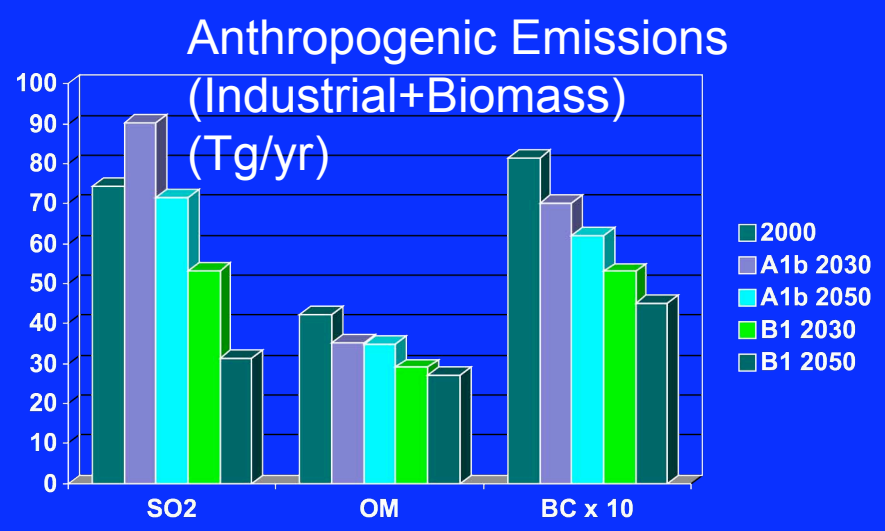
Why is it difficult to infer future sulfate burden?

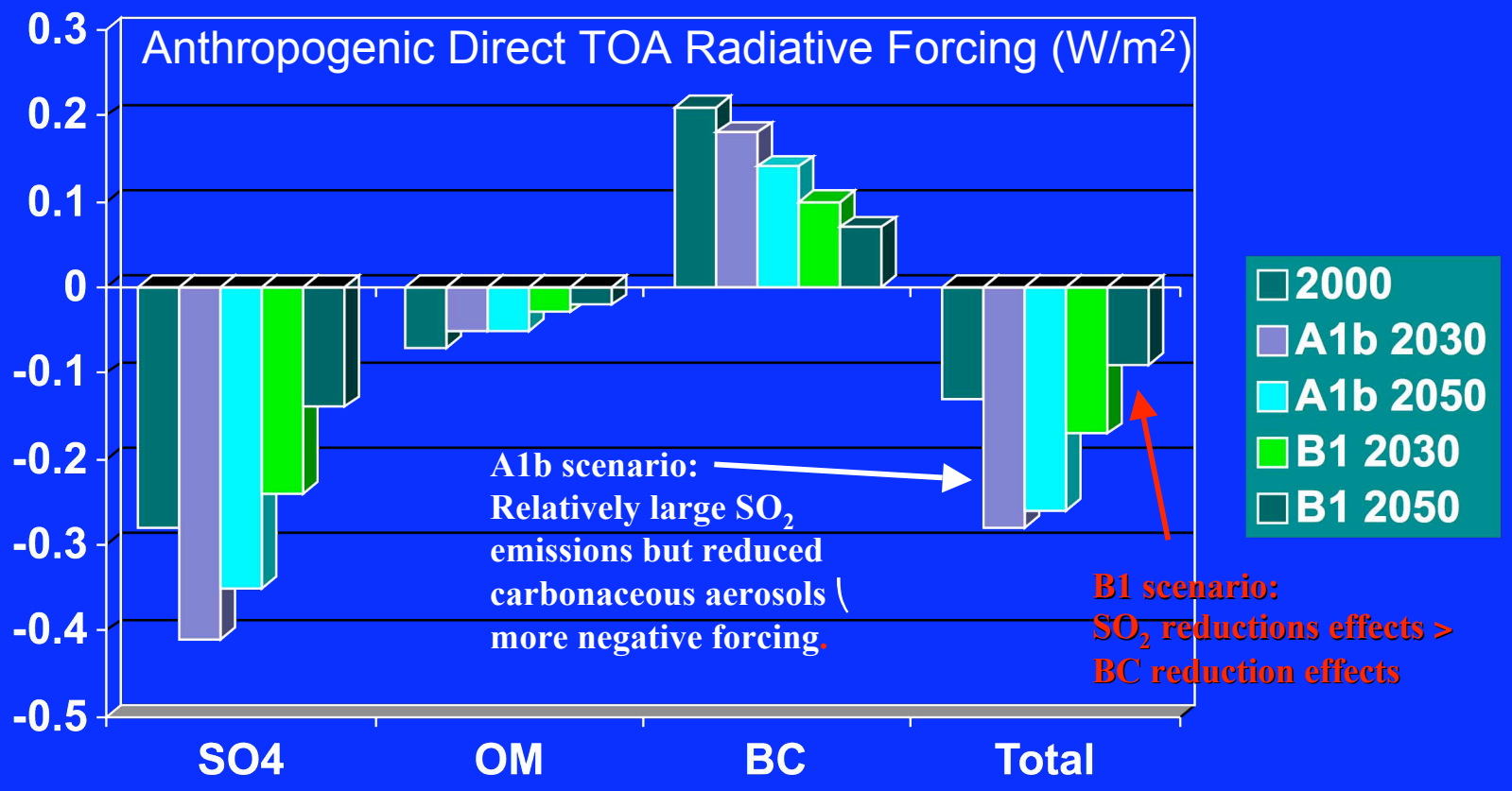
- Recall that in regions such as Europe and China sulfate production is presently oxidant limited. So reducing SO_2 emissions from such regions will not result in a proportional decrease in sulfate.

Change in SO2 emissions between future and present



Anthropogenic forcing for future scenarios: For these 2 scenarios, cleaner is warmer





Conclusions of Aerosol Model Experiments

- **Big emitters (e.g. U.S., Europe, China, India) should derive direct benefit in surface air quality from cutting aerosol emissions**

- (Aerosol) sectors best targeted to reduce global warming: ***Transport*** and ***Residential*** since these have largest black carbon component. However based on these (fixed SST) simulations, the forcing benefits appear to be modest.

Can we effectively target subsectors (diesel) and reduce BC significantly more than SO_2?

Reducing industrial and power emissions could result in significantly decreased negative aerosol forcing (adding to global warming).

Conclusions of Aerosol Model Experiments, cont'd

- Comparing A1b and B1 future scenarios, the cleaner option has a less negative forcing, due to the greater reduction in sulfate (relative to BC) (adding to global warming).

- Carbonaceous aerosols appear to show linear relation between emission and (TOA instantaneous) forcing globally, although some regions do not (e.g. North America and India).

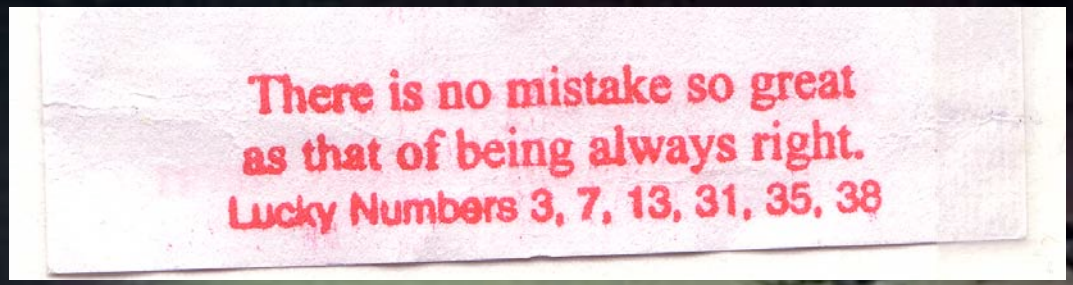
- Care should be taken when inferring response of sulfate forcing to changes in SO_2 emission due to effects of oxidant limitation.

Limitations of Aerosol Model Experiments

- We have assumed external mixing of aerosols. (Internal mixing may decrease importance of sulfate forcing.)

- Simulation with full climate effects (including indirect and semi-direct effects) and climate response (with ocean response) will reveal non-linearity between black carbon emission and climate impact. For example, BC impact on temperature is reduced for high altitude BC (Hansen et al., 2005).

Chinese restaurant fortune cookie:



Northern lights over Fairbanks, Alaska

Haze from Asian Forest fires

The Bible:

And if anyone thinks that he knows anything,
he knows nothing yet as he ought to know.
1 Corinthians 8:2

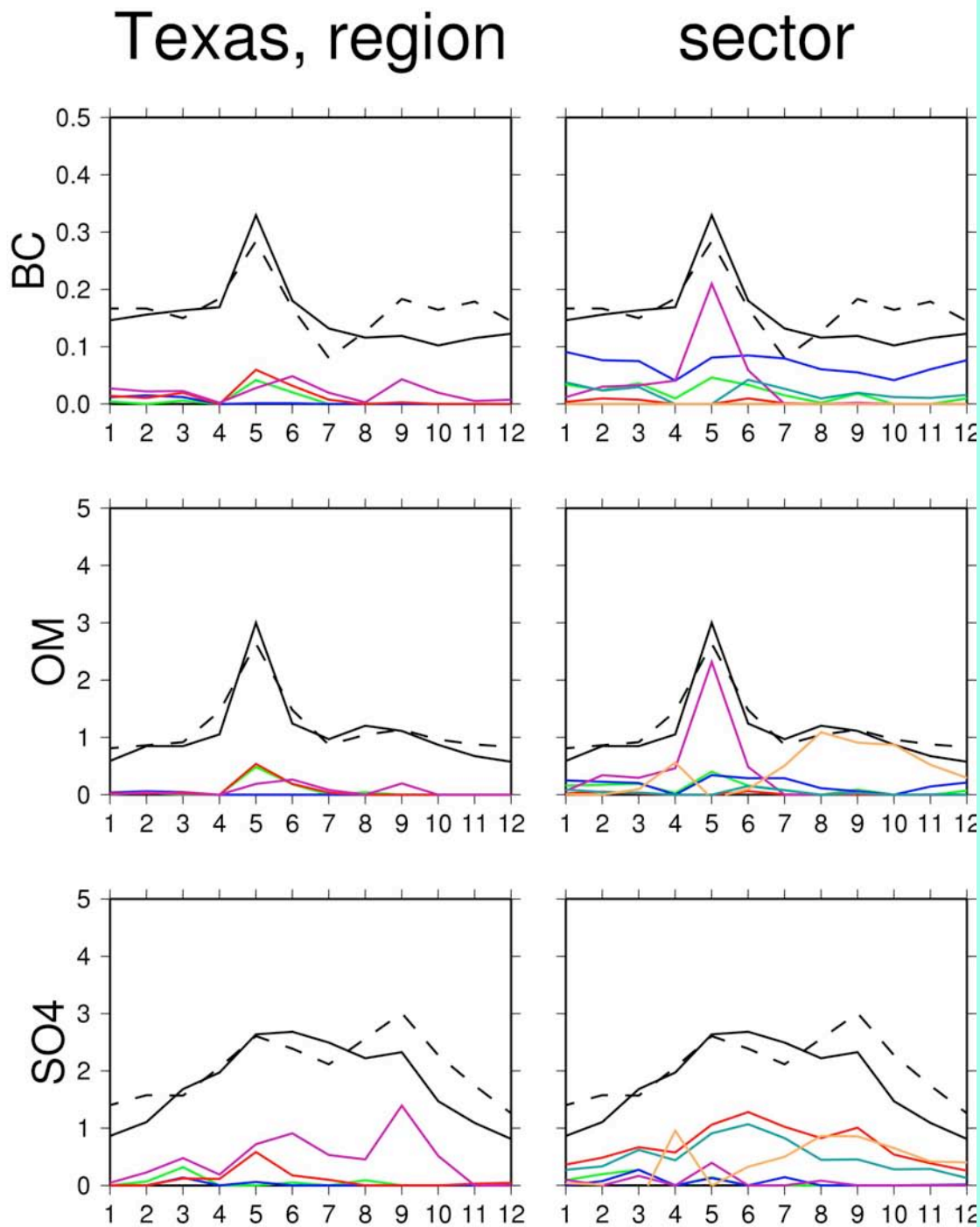
Texas, U.S.
Pollution isn't local

Regions

- N America
- Europe
- China
- India

Sectors

- Transport
- Natural
- Residential
- Power
- Biomass
- Industry



Denali, Alaska

Regions

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- Europe
- China
- India

Sectors

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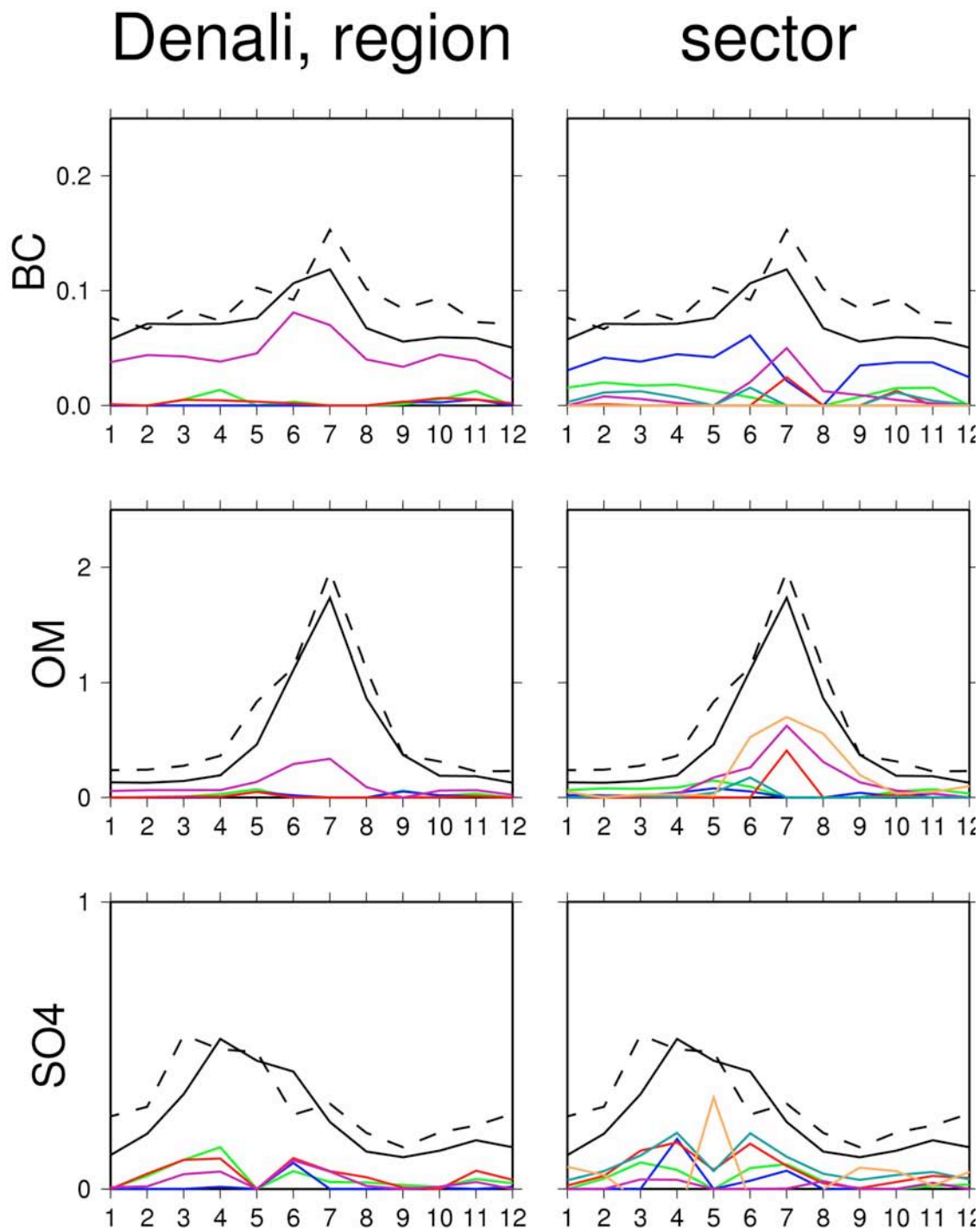


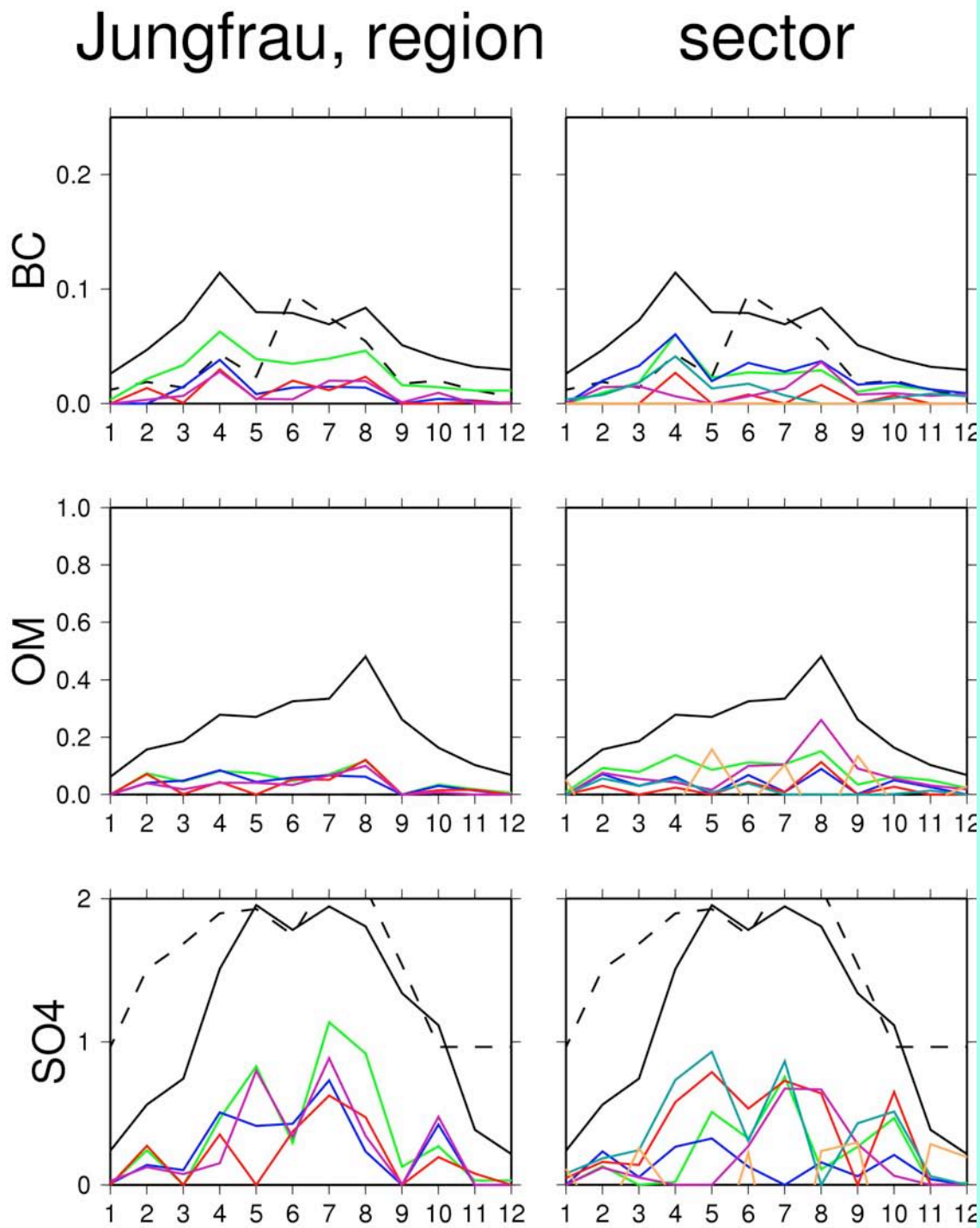
Alps

Regions

- N America
- Europe
- China
- India

Sectors

- Transport
- Natural
- Residential
- Power
- Biomass
- Industry



Bombay, India

Regions

- N America
- Europe
- China
- India

Sectors

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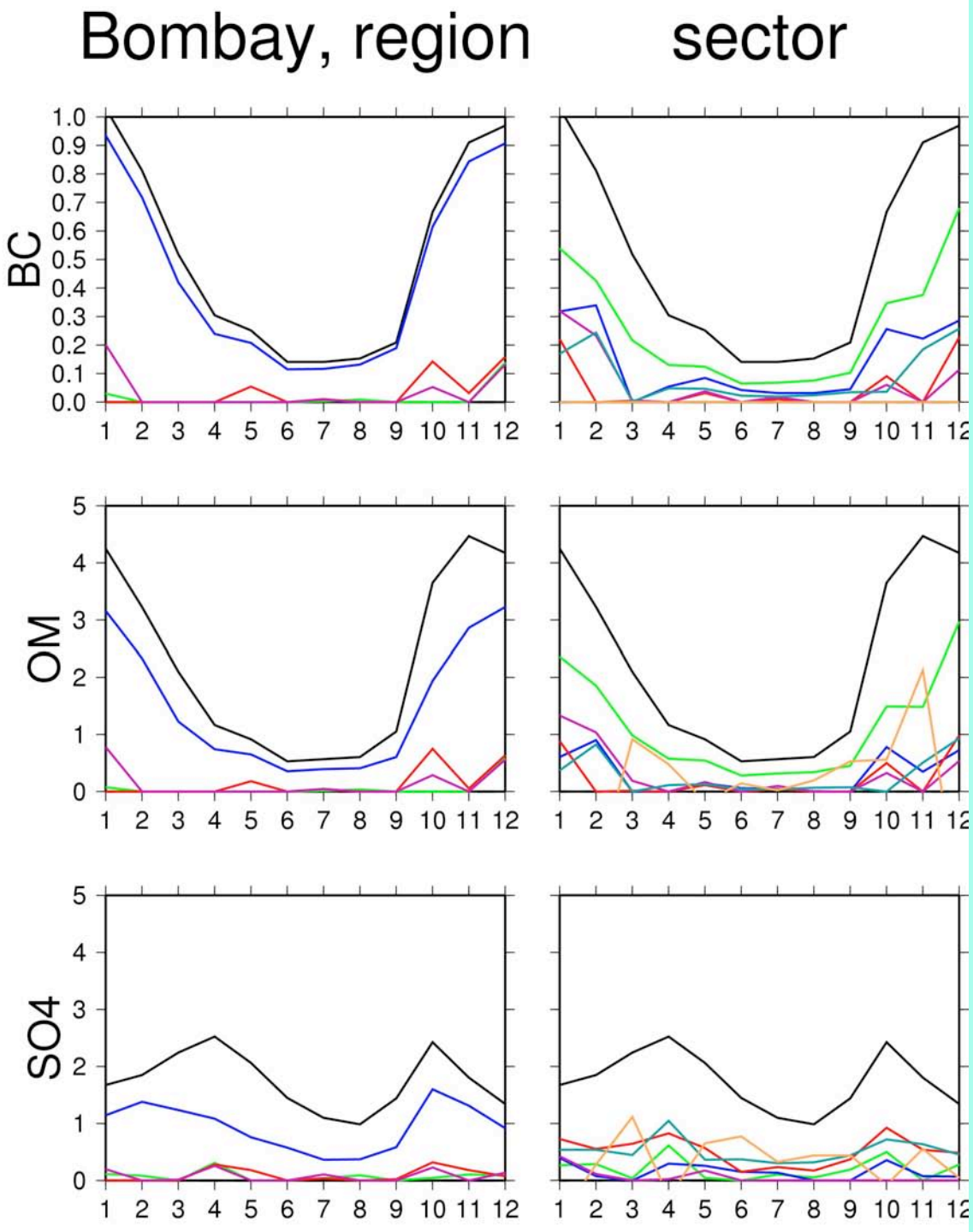
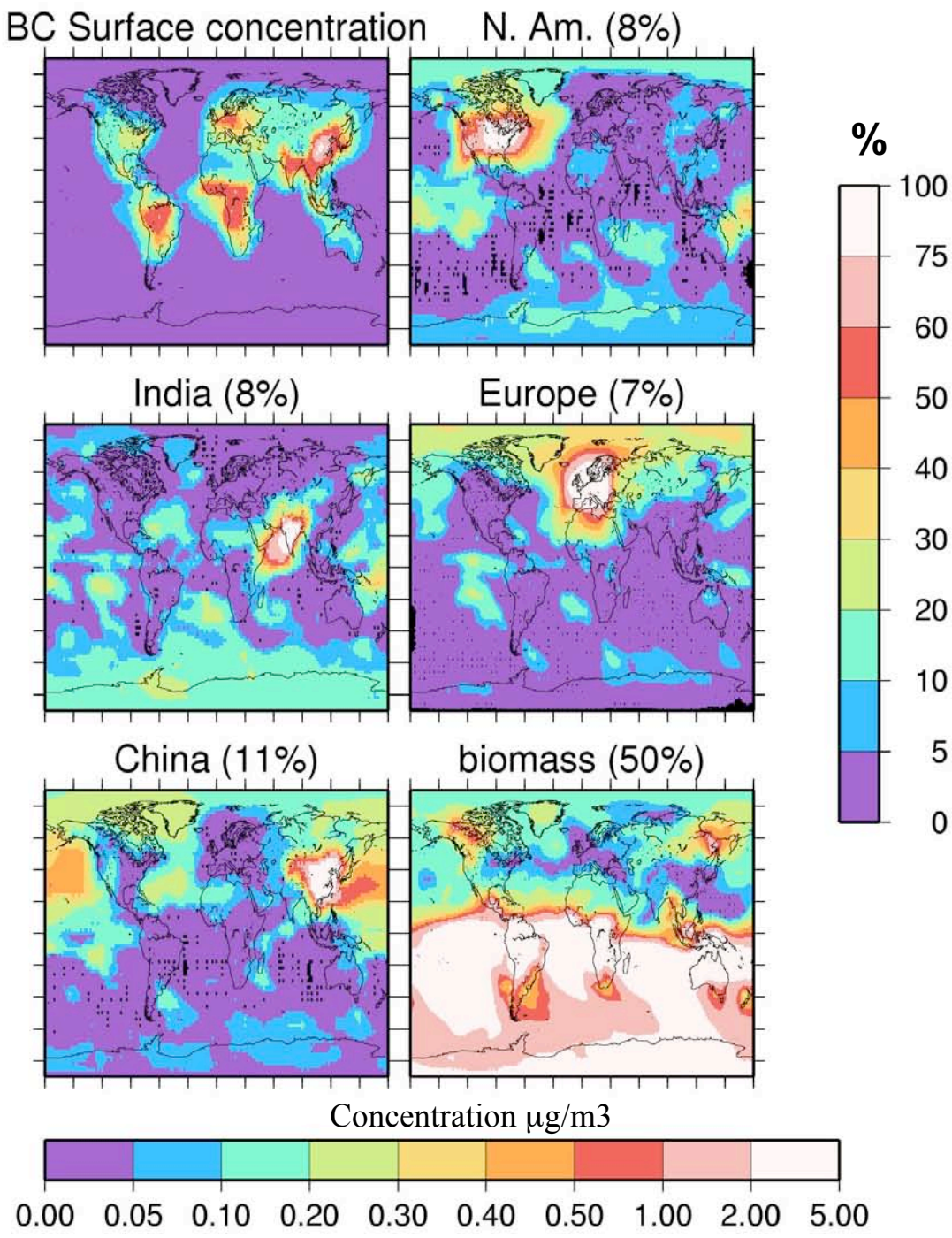
- Industry

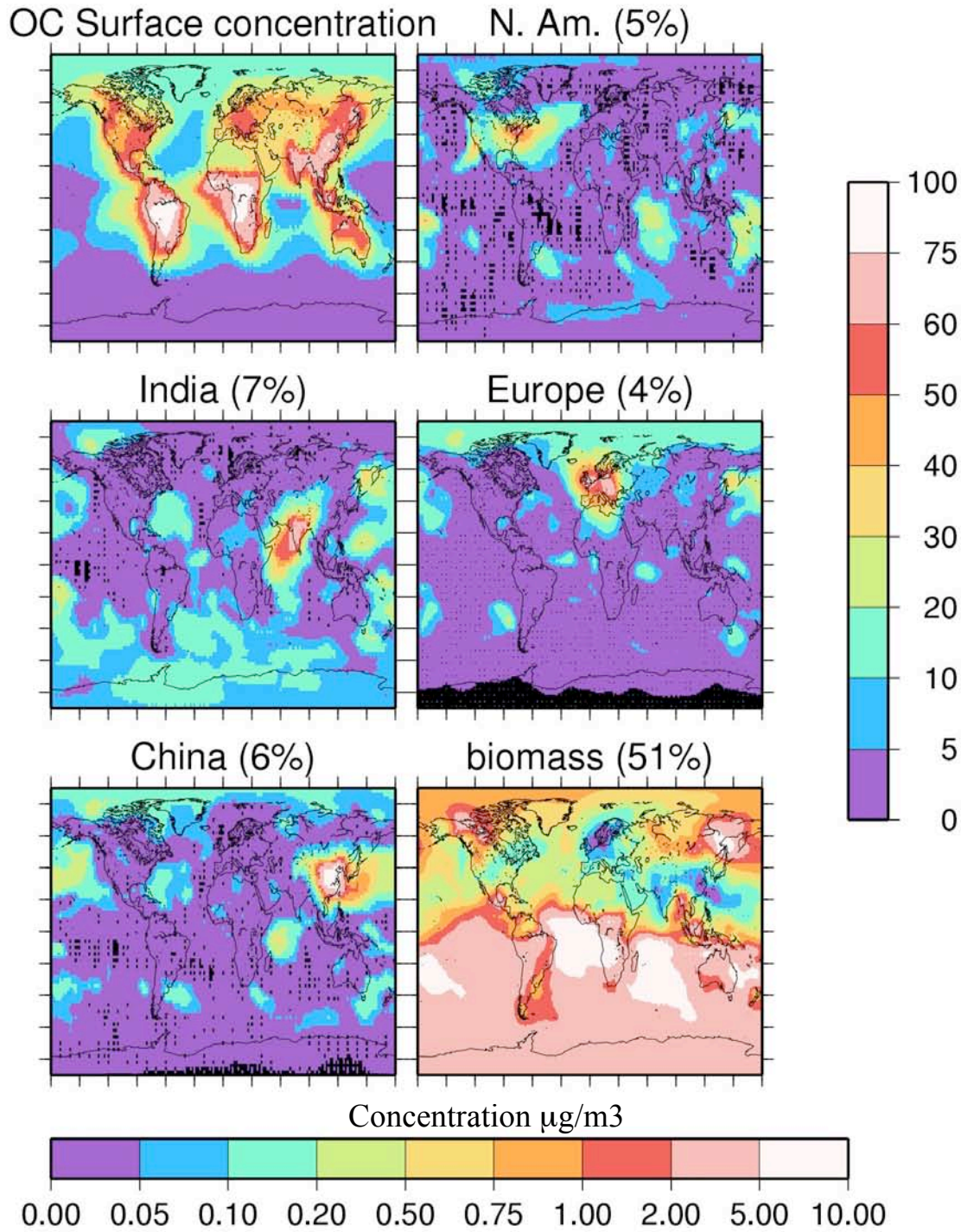


How much black carbon does each region contribute to surface concentrations?

- If a region eliminated BC, how clean would its surface air become?

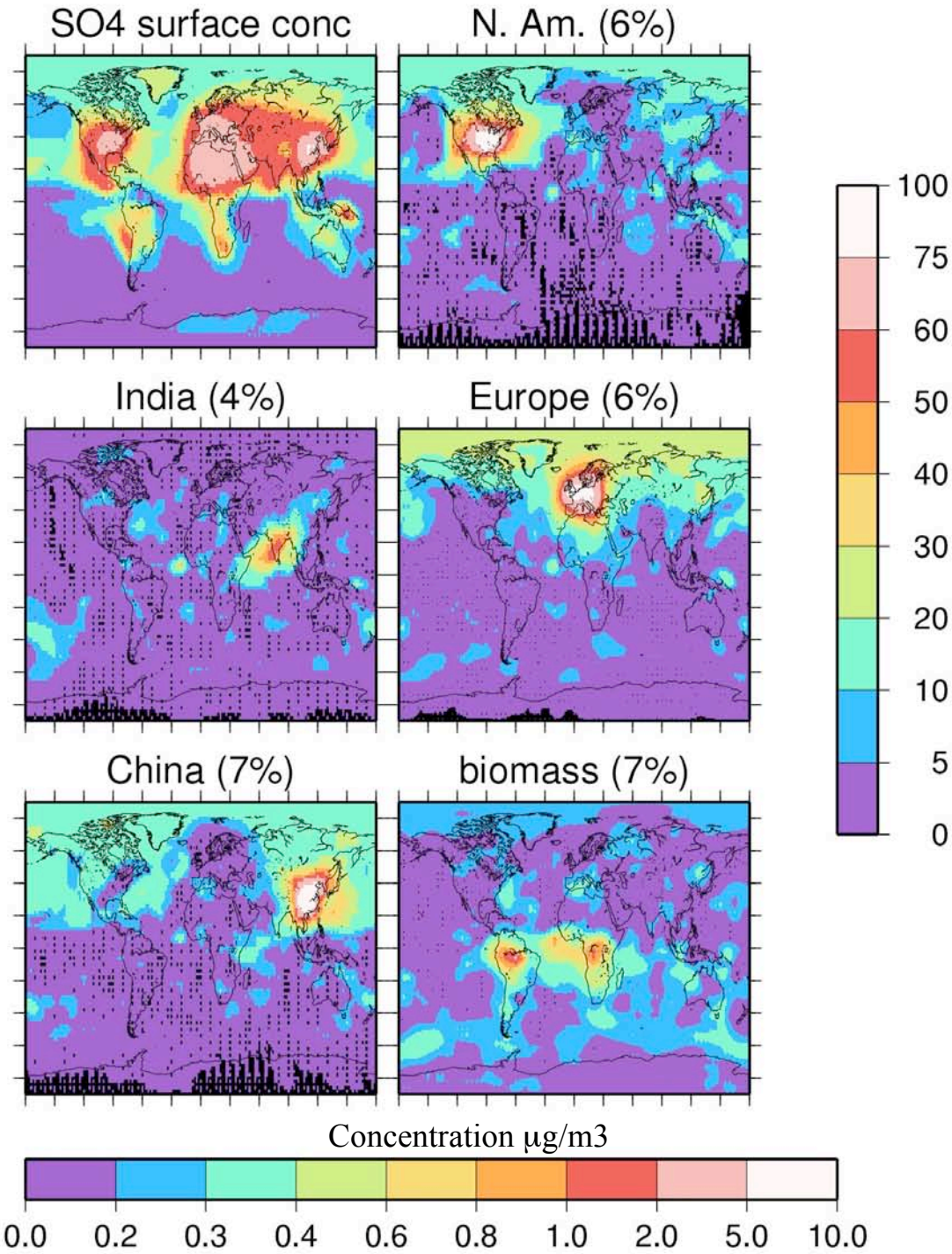


How much organic carbon does each region contribute to surface concentrations?

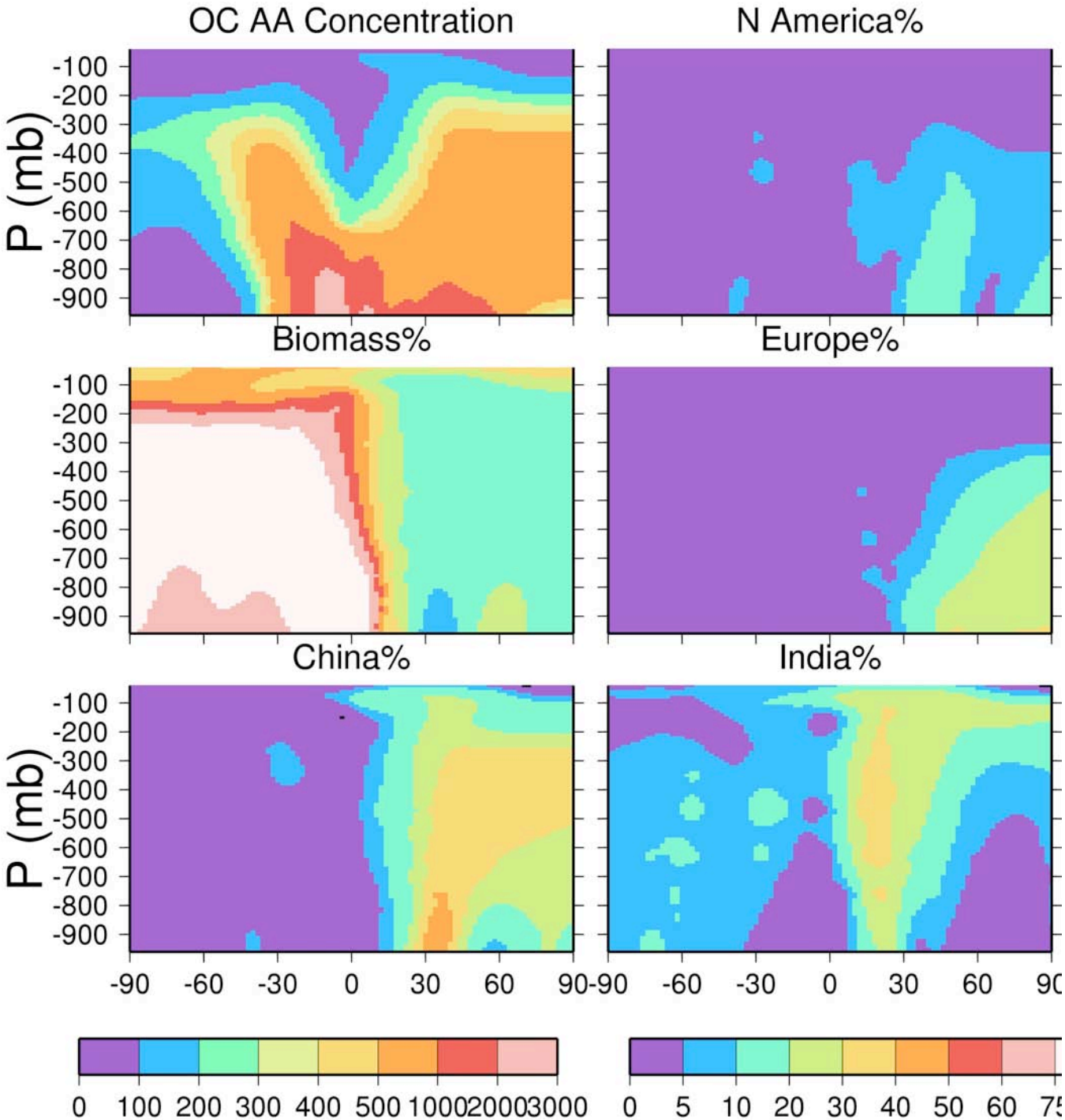


How much sulfate does each region contribute to surface concentrations?

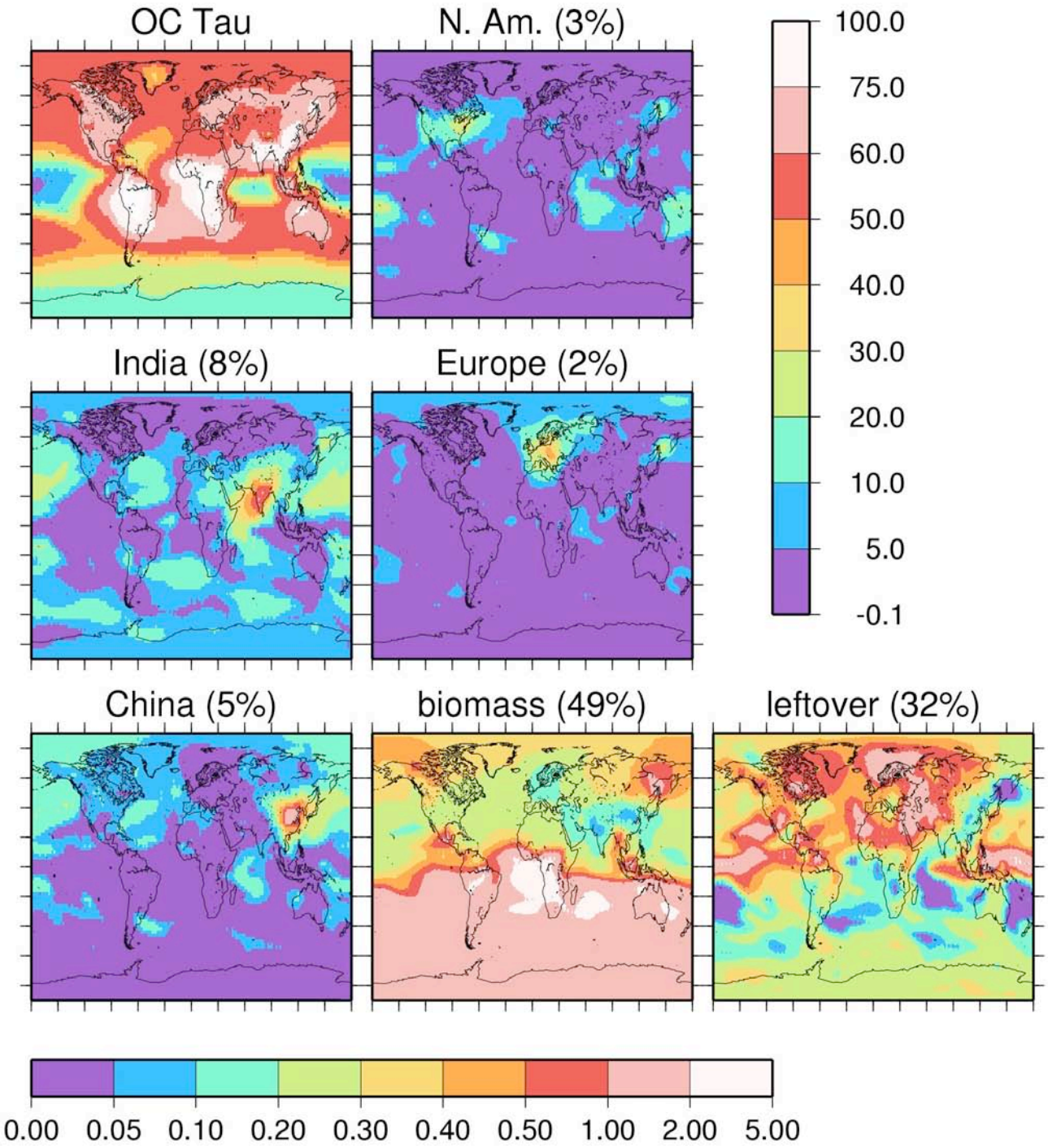
- Europe dominates Arctic sulfate at the surface



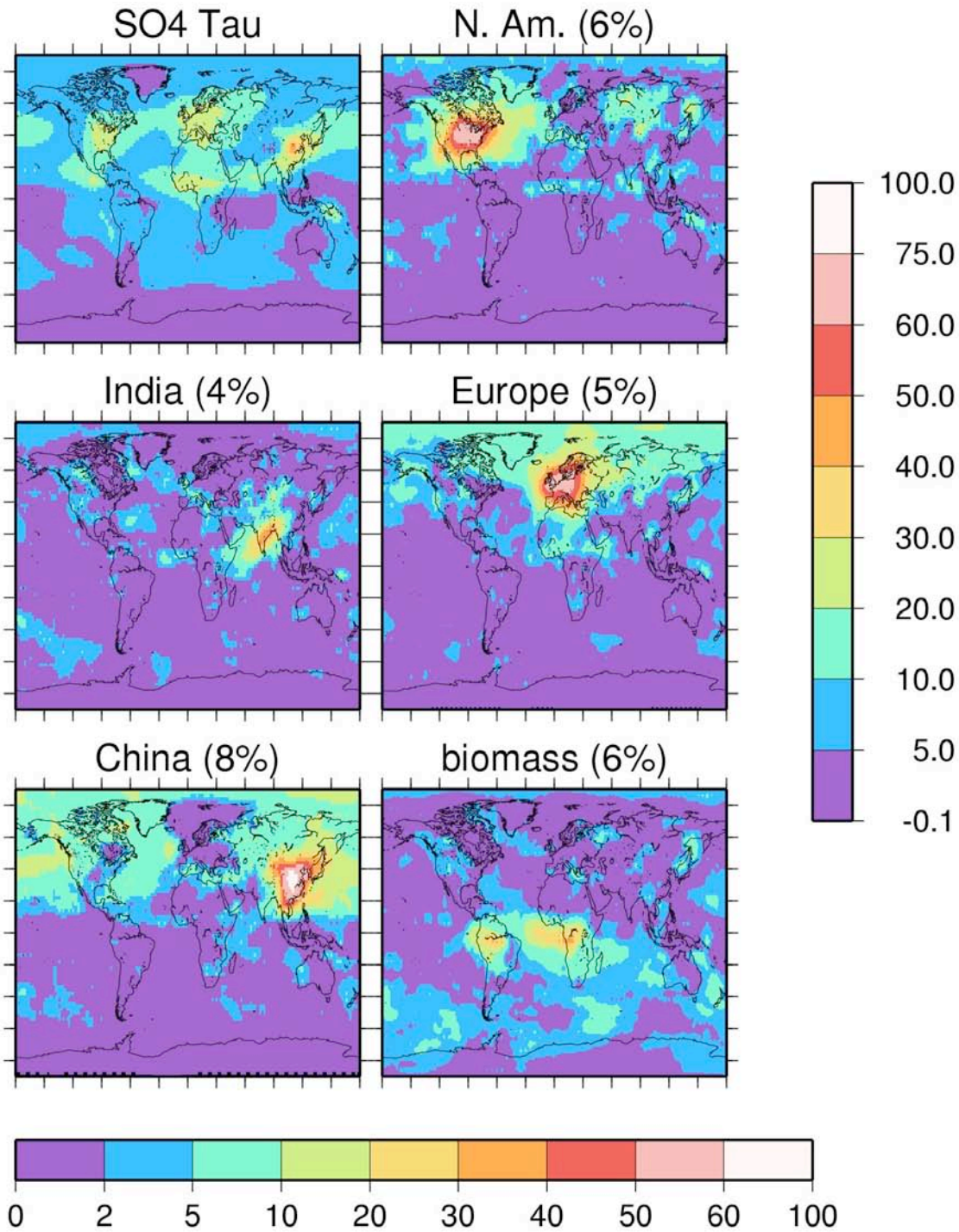
Organic matter concentration: altitude-latitude view



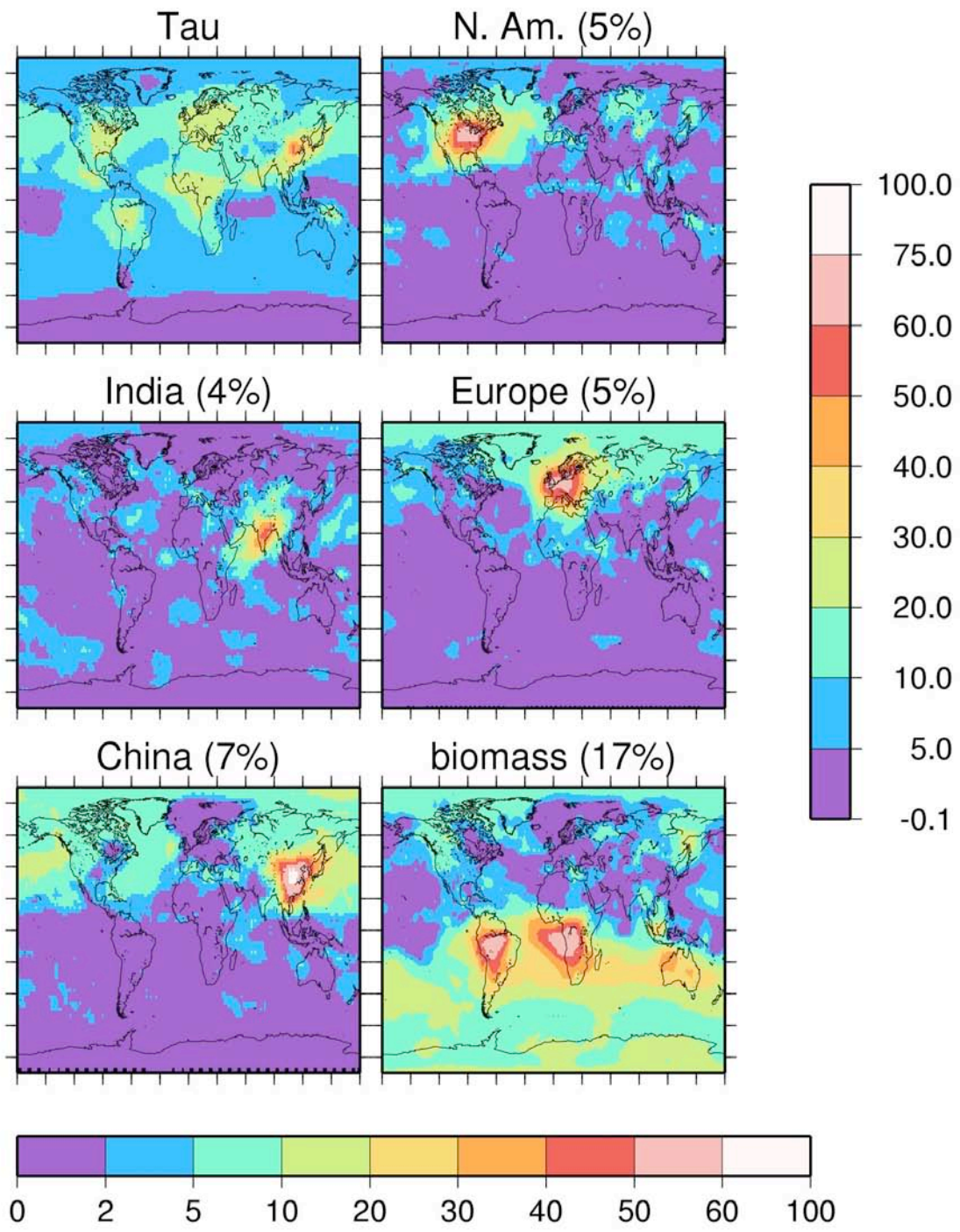
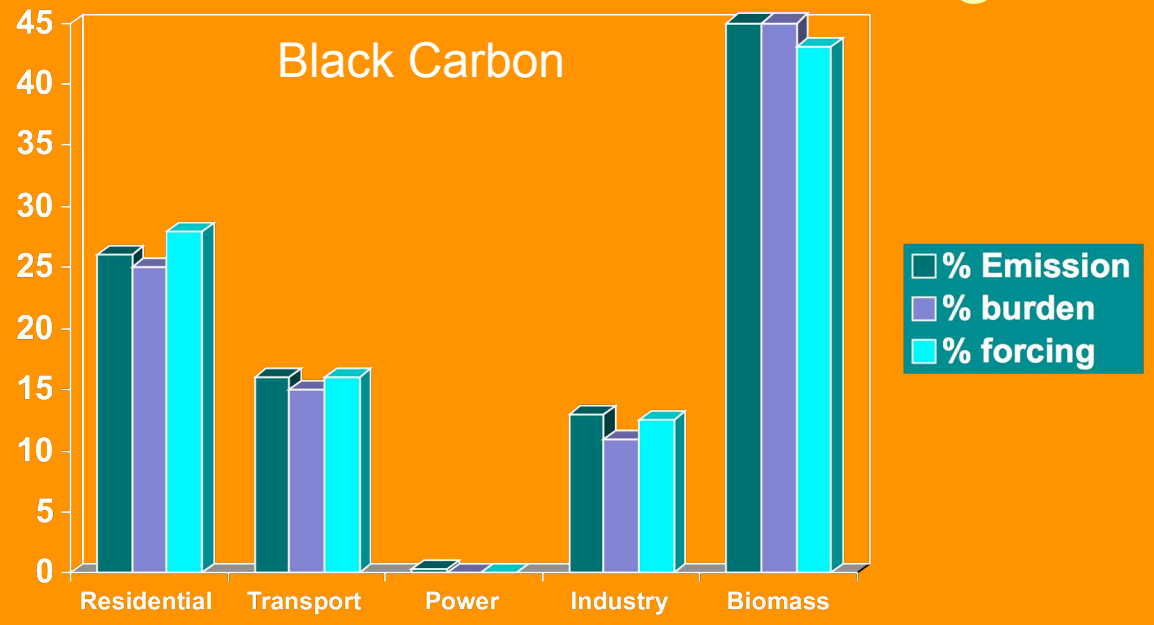
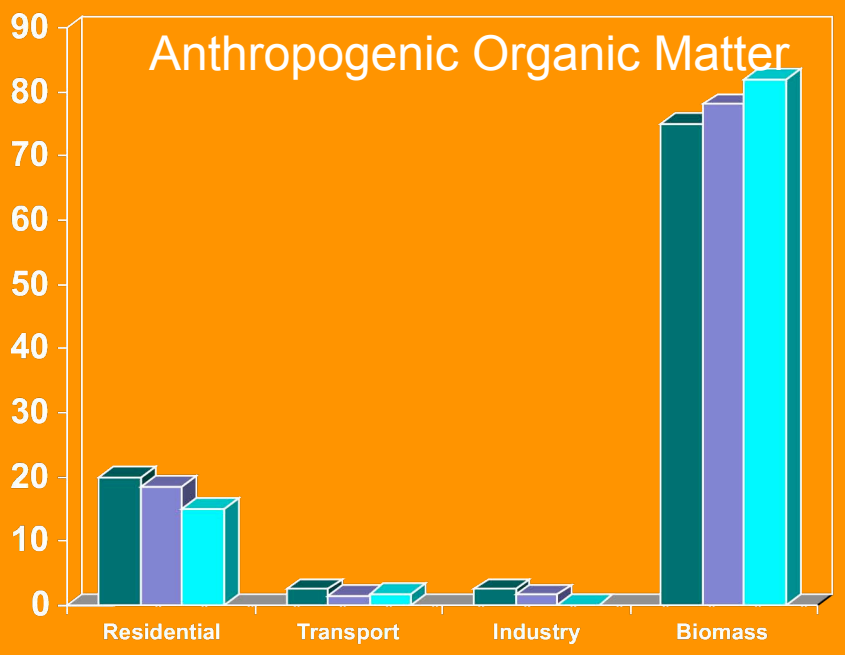
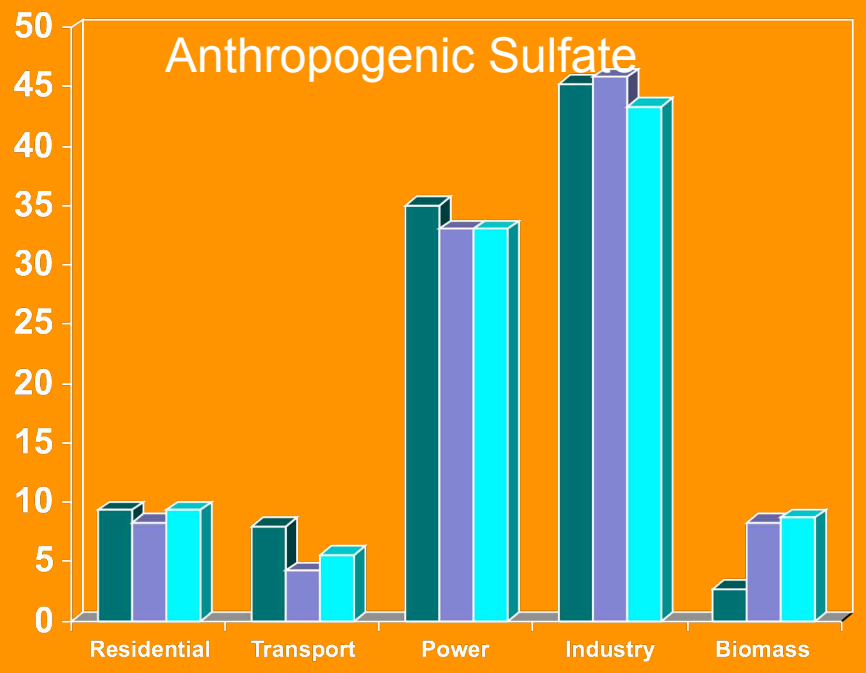
- Most Arctic organic matter is from biomass burning



Sulfate optical thickess: regional attribution



Total optical thickness: Regional attribution



Emission, Burden, Forcing: Sectoral distributions