

# Multi-decadal variation of atmospheric aerosols and their impacts – Hindcast analysis

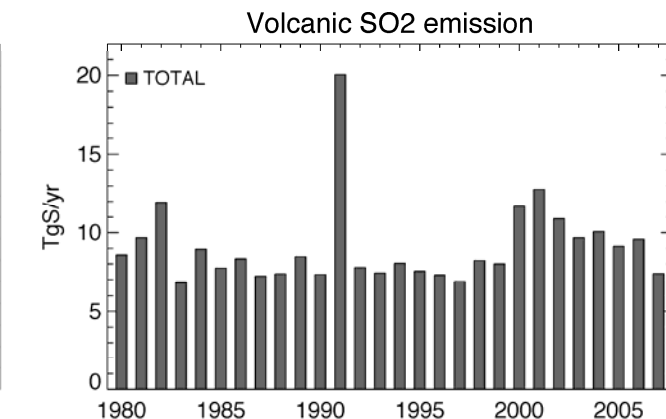
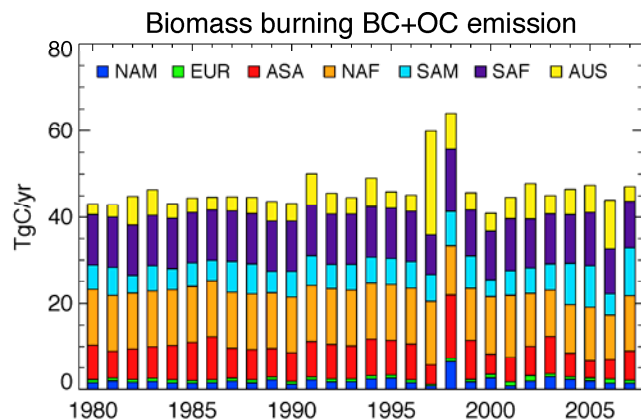
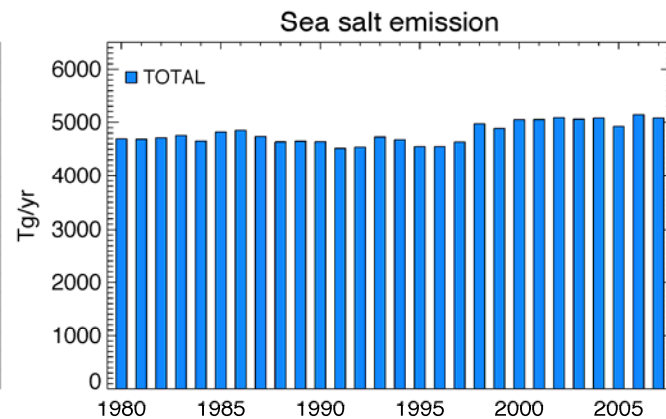
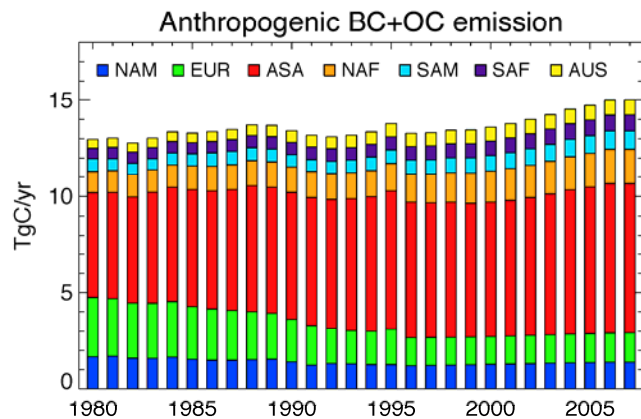
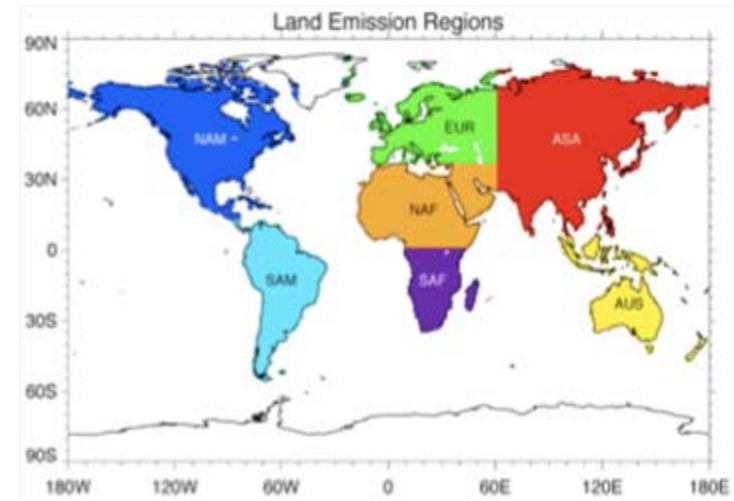
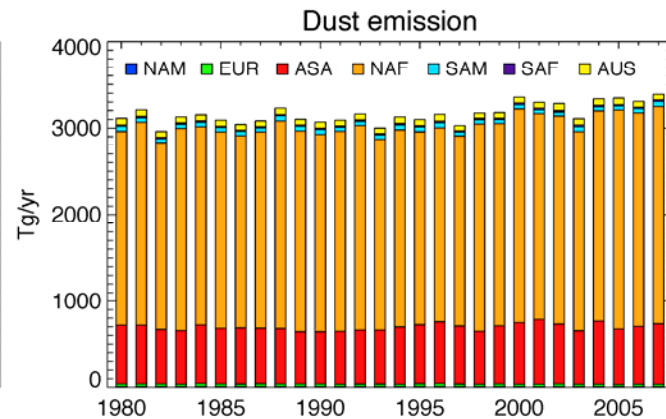
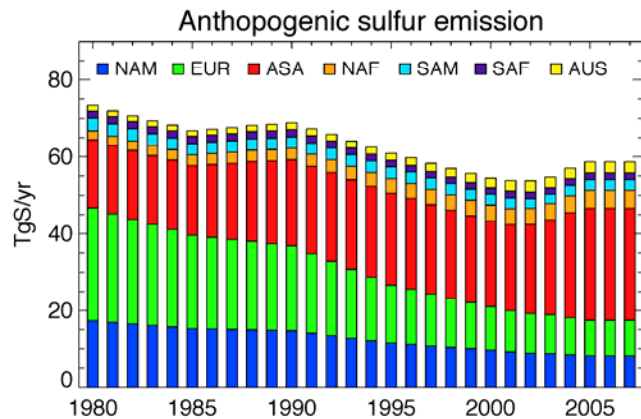
Mian Chin<sup>1</sup>, Thomas Diehl<sup>1,2</sup>, Qian Tan<sup>1,2</sup>, Dongchul Kim<sup>1,2</sup>,  
David Streets<sup>3</sup>, Hongbin Yu<sup>1,4</sup>, Huisheng Bian<sup>1,5</sup>, Stefan  
Kinne<sup>6</sup>, Patricia Quinn<sup>7</sup>

<sup>1</sup>NASA Goddard Space Flight Center, USA <sup>2</sup>Universities Space Research Association, USA <sup>3</sup>Argonne National Laboratory, USA <sup>4</sup>University of Maryland, College Park, USA <sup>5</sup>University of Maryland, Baltimore County, USA <sup>6</sup>Max Planck Institute, Hamburg, Germany <sup>7</sup>NOAA PMEL, USA

# Topics of analyzing hindcast model experiments

- A2 HC model output:
  1. Multi-decadal aerosol trends and their effects on surface radiation trends – dimming/brightening
  2. Aerosols over Asia – magnitudes, trends, model problems
  3. Multi-decadal variations of dust aerosols
  
- Additional “tagged” experiments:
  4. Arctic haze – variations of source attribution
  5. Stratospheric sulfate aerosol trends – volcanic or anthropogenic

# Anthropogenic and natural emissions of aerosols and precursors – 1980 to 2007

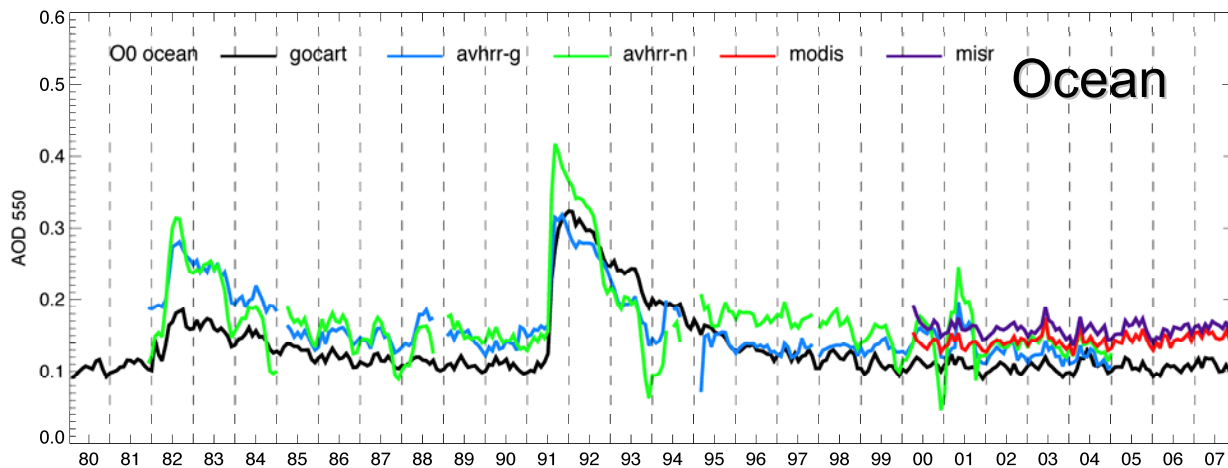
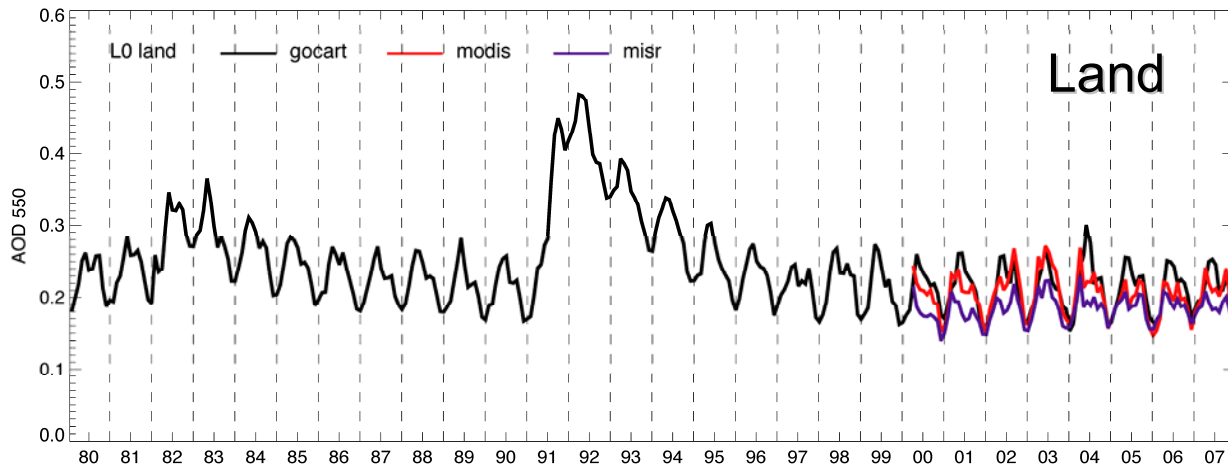


Anthropogenic emission:  
 ▶ Decreased over North America and Europe, increased over Asia and other regions

Biomass burning and natural emissions:  
 ▶ Varying from year to year (and place to place)

# 1. Multi-year variation of AOD and surface radiation

## Comparison of monthly average AOD over land and ocean

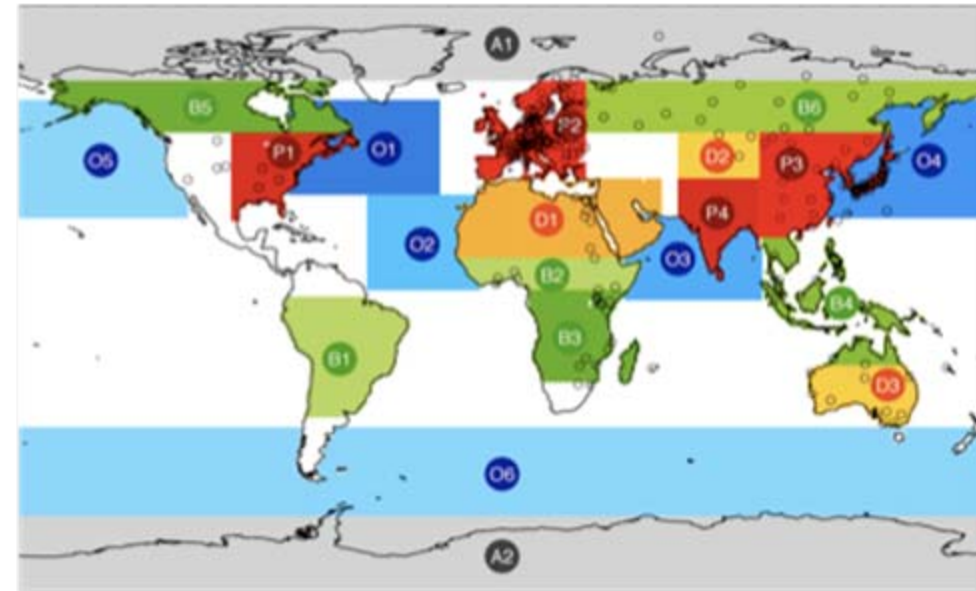
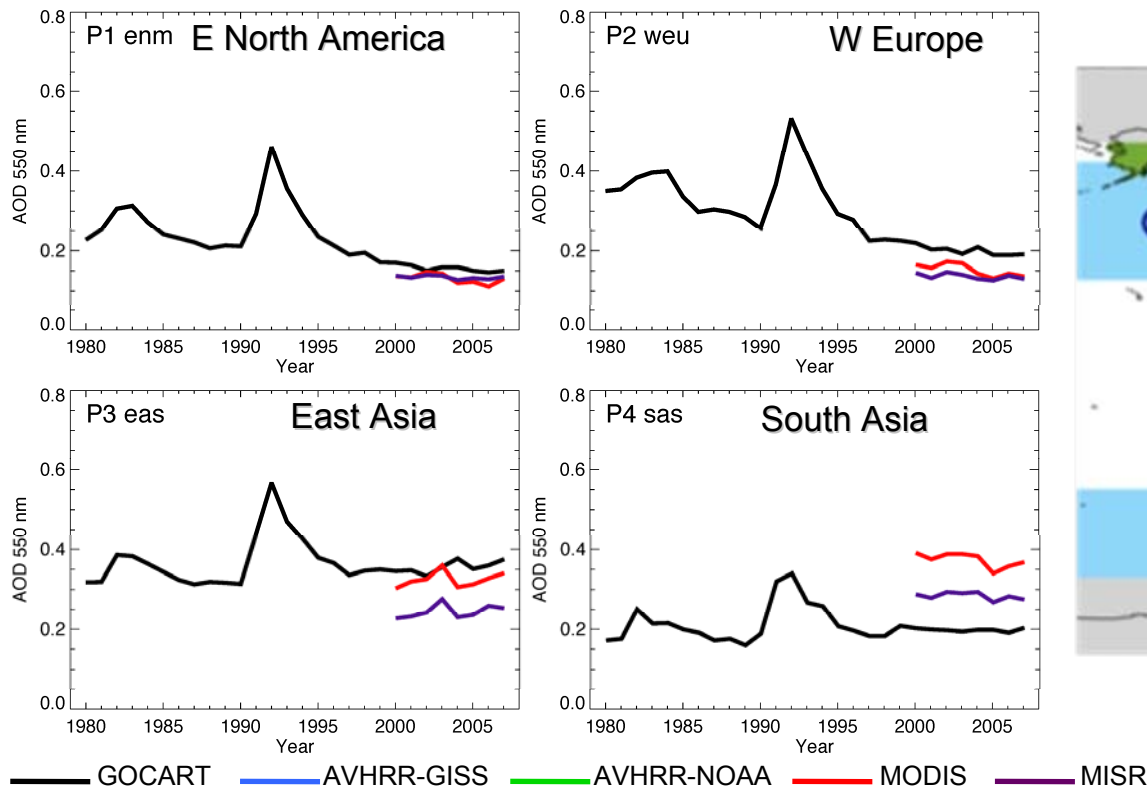


— GOCART — AVHRR-GISS — AVHRR-NOAA — MODIS — MISR

- Over land: Model simulated AOD agrees with MODIS and MISR
- Over ocean: model is in general lower than satellite data
- There are also differences among different satellite datasets

# AOD trends over pollution source regions

AOD trends over pollution regions (de-seasonalized)

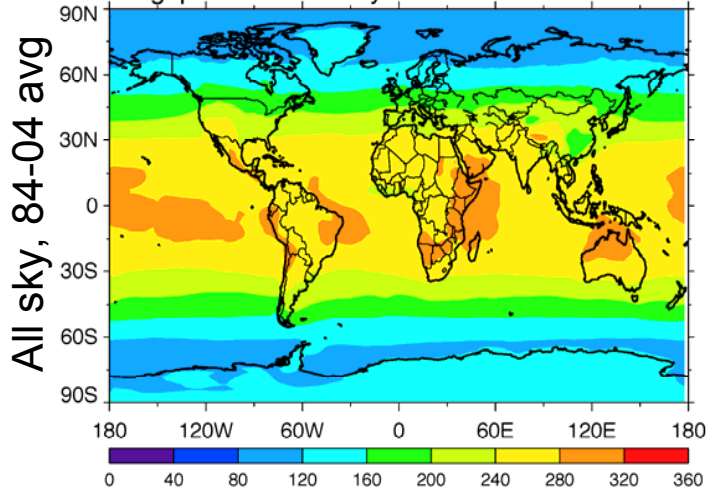


- Over E North America and Europe: AOD decreasing
- Over E Asia: AOD increasing
- El Chichon and Pinatubo volcanoes have large global influences
- Modeled AOD is much lower than MODIS and MISR over S Asia

# Climatology (1984-2004) of downward surface shortwave radiation (SSR) – All sky

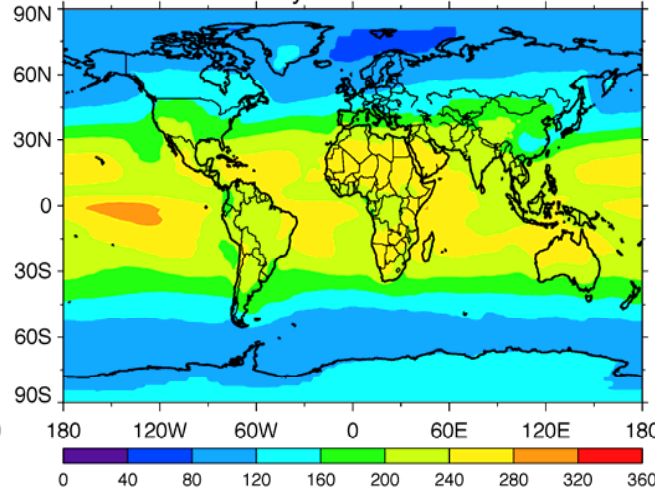
## GOCART

g4p0e043tld All Sky Sfc SW dn 1984-2004



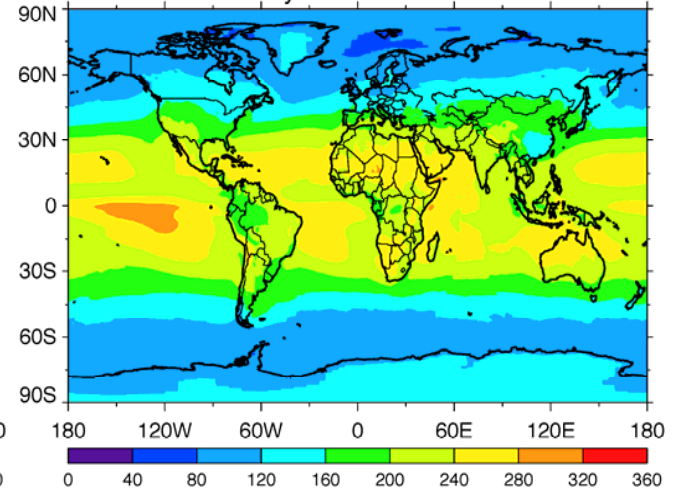
## ISCCP

ISCCP All Sky Sfc SW dn 1984-2004



## SRB

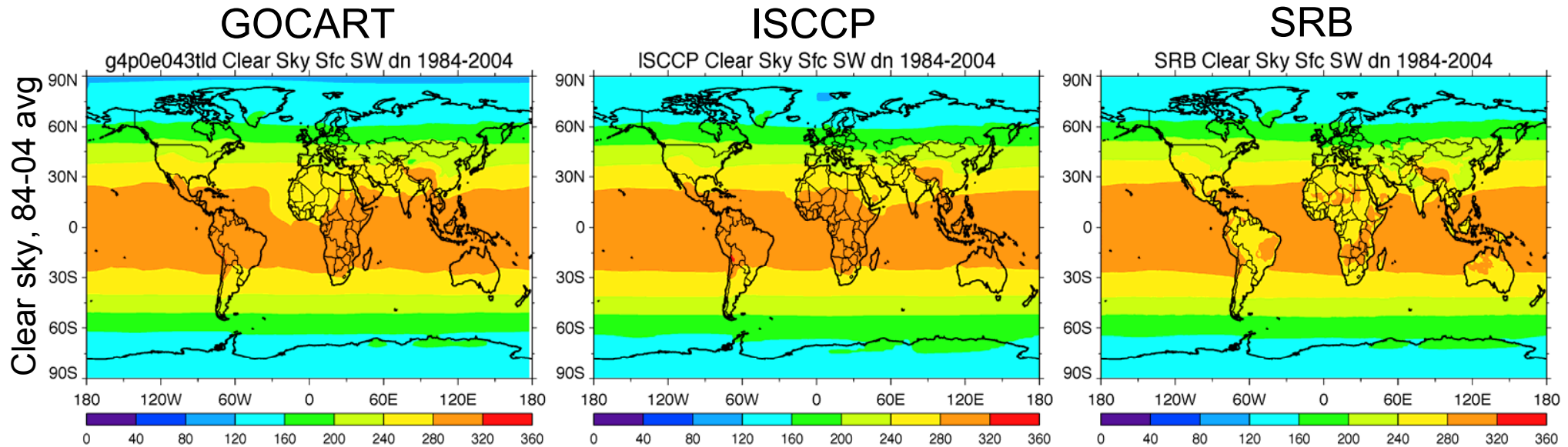
SRB All Sky Sfc SW dn 1984-2004



- Under all sky condition, model calculated surface SWDF is about 20 – 60  $W m^{-2}$  higher than that from ISCCP and SRB, most likely because of the difference in cloud fields



# Climatology (1984-2004) of SSR – Clear sky

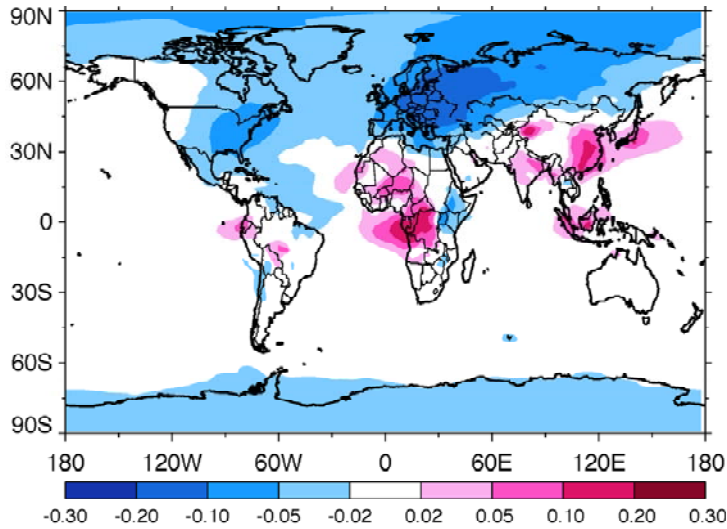


- Under clear sky condition, the model agrees with ISCCP and SRB in most location (Note: clear sky data from ISCCP and SRB are extracted with cloud fraction < 10%)

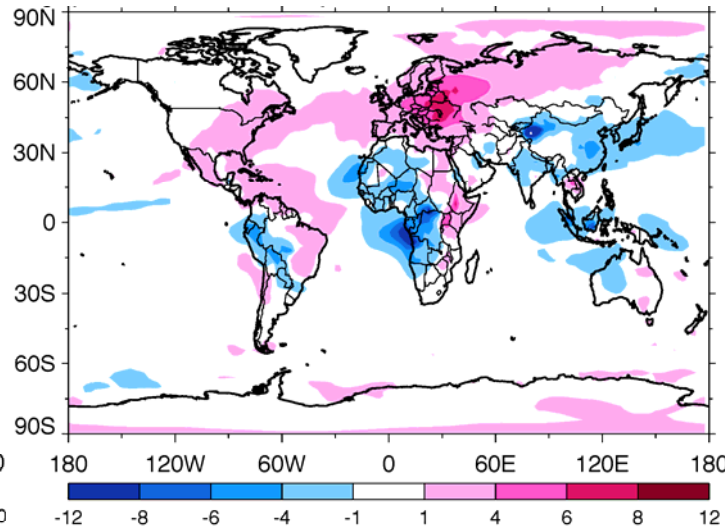
Aerosol effects on SSR will be best revealed in clear sky conditions because cloud forcing is much larger than aerosol

# Relationship between changes of AOD and SSR

$\Delta$  AOD, [2000-2004] – [1985-1989]

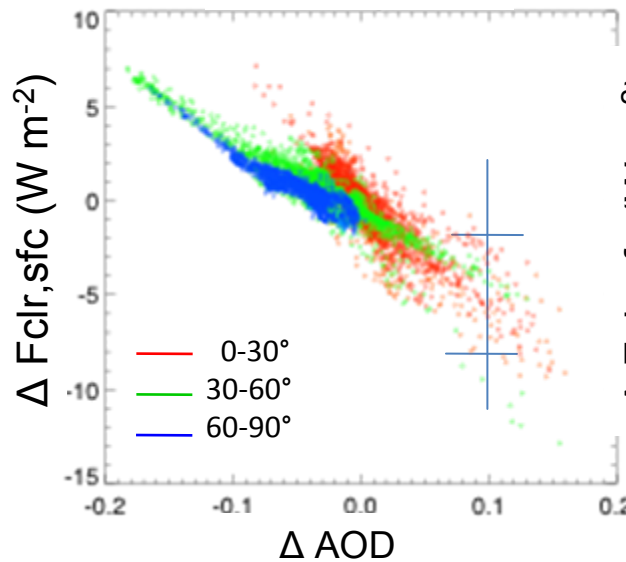


$\Delta$  Fclr,sfc, [2000-2004] – [1985-1989]

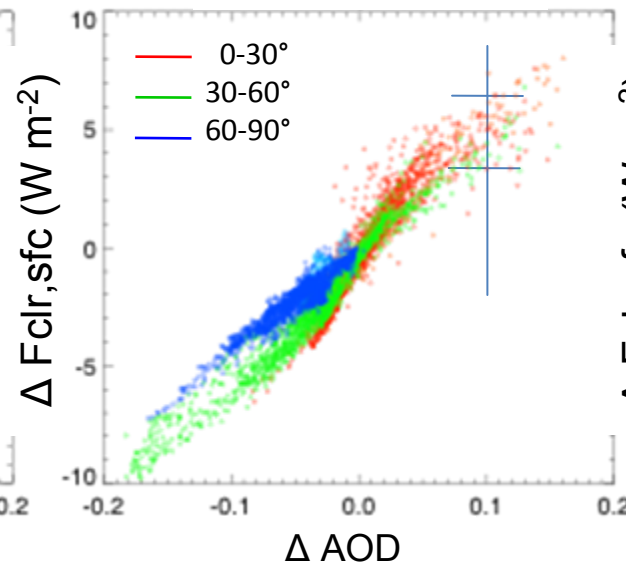


- Under clear sky conditions, aerosols control the change of solar radiation reaching the surface
- “Dimming” efficiency dep. on location, season, and aerosol type

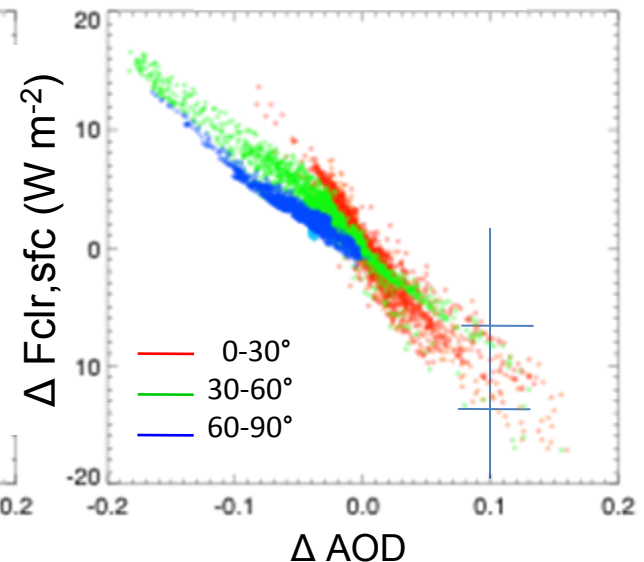
Clear sky total



Clear sky diffuse



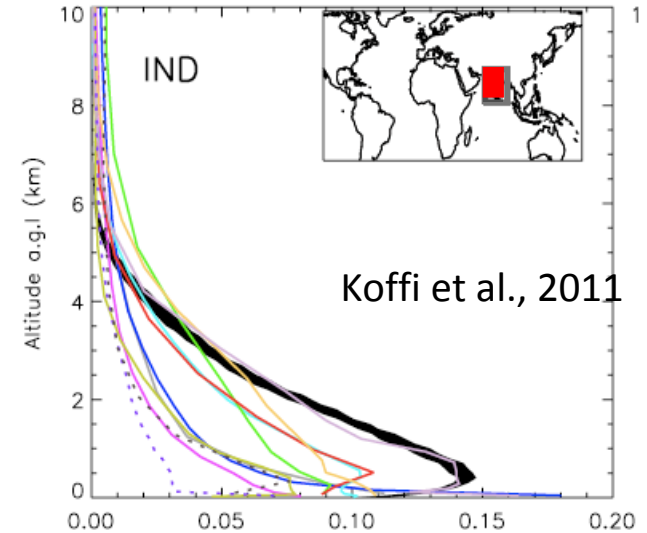
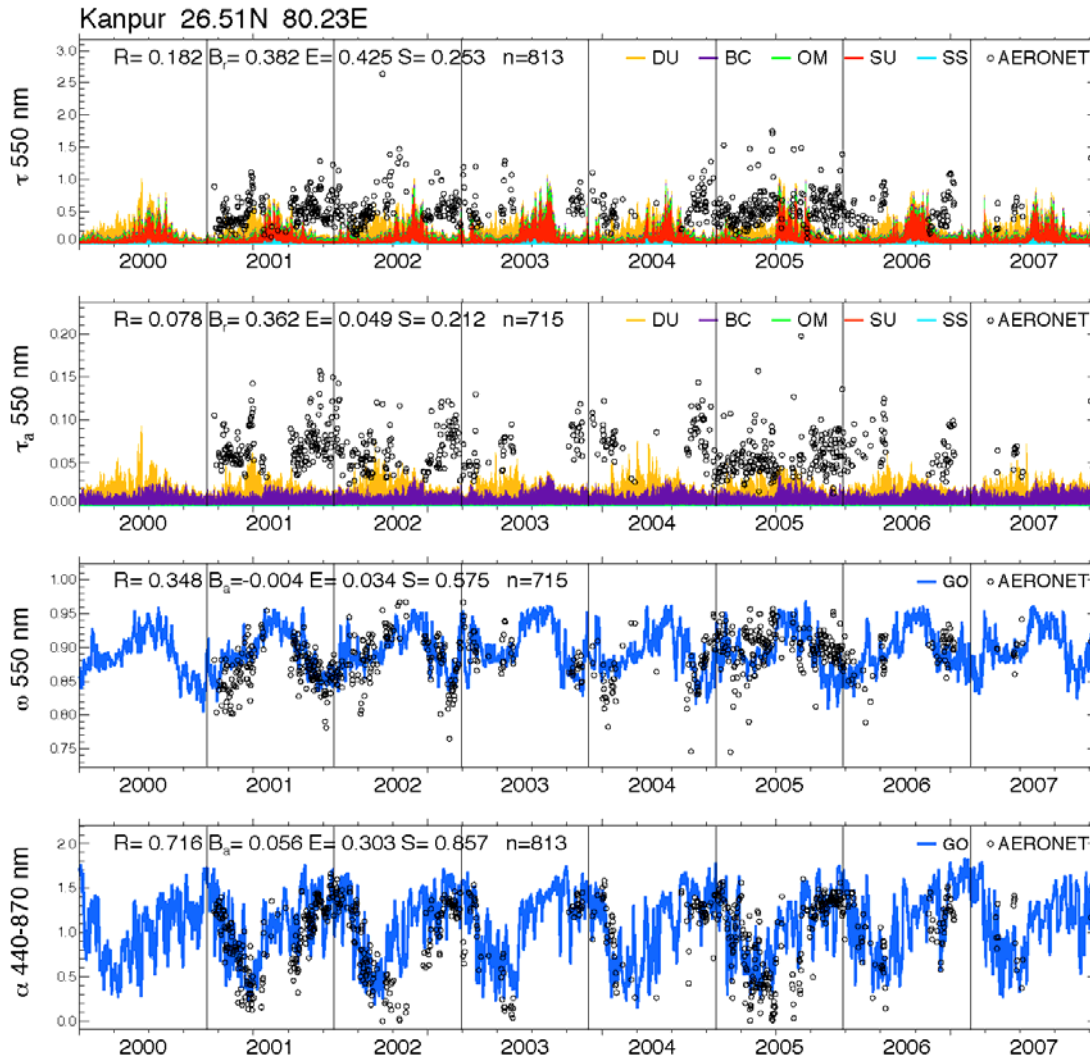
Clear sky direct





## 2. Aerosols over Asia – most problematic place for a lot of models

Chin et al., 2009

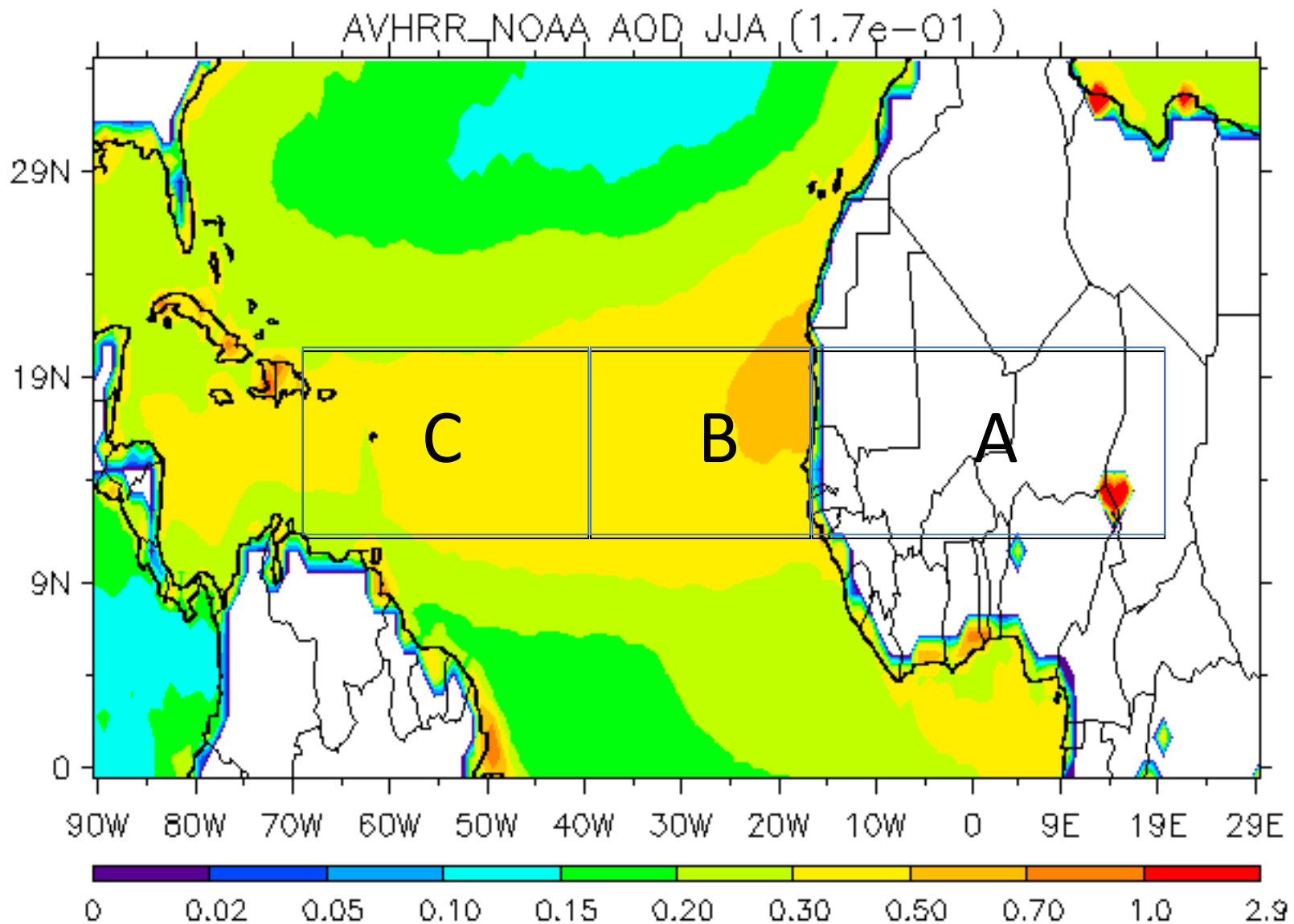


Models usually significantly underestimate aerosol amount over India (and China too)

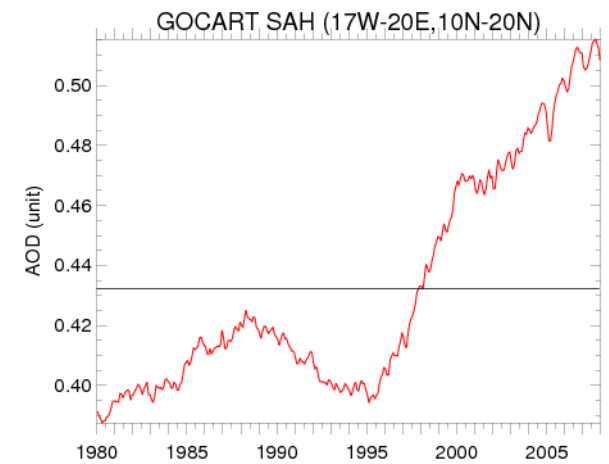
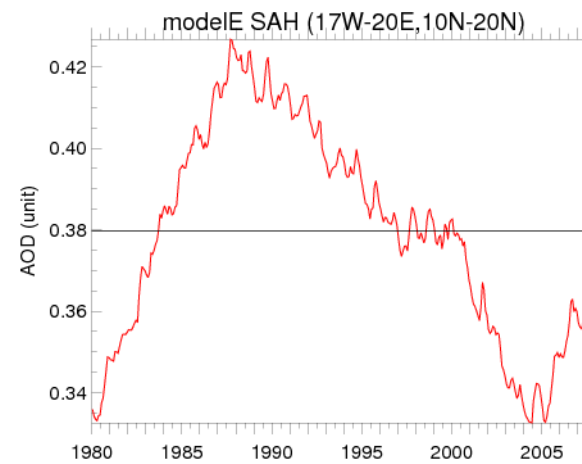
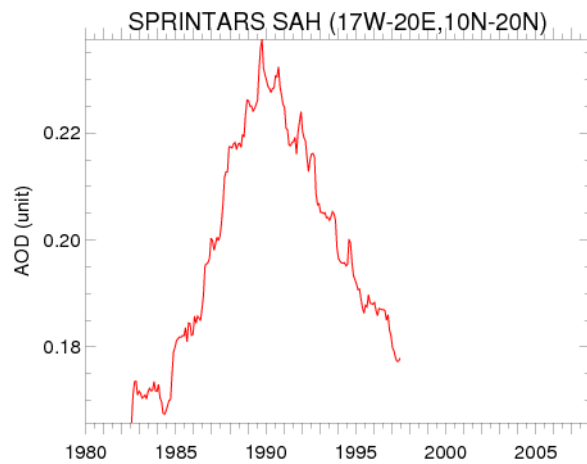
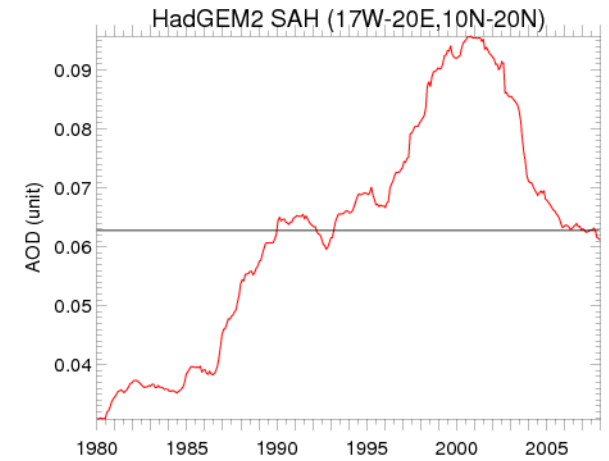
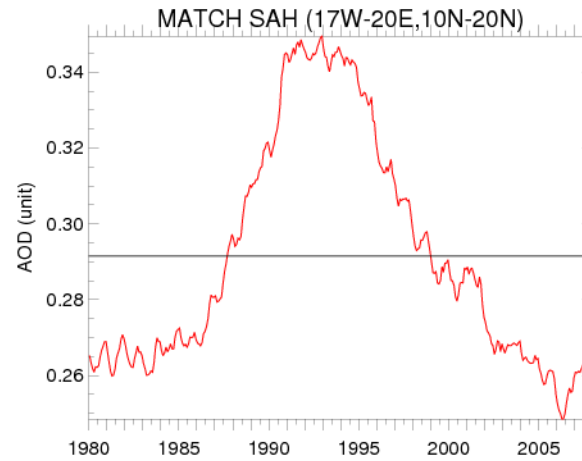
Shortage of accessible data may prevent break-through progress in model improvements

Currently we have obtained some new and more detailed emission over China and India and limited surface data as well so we plan to have a more in-depth analysis

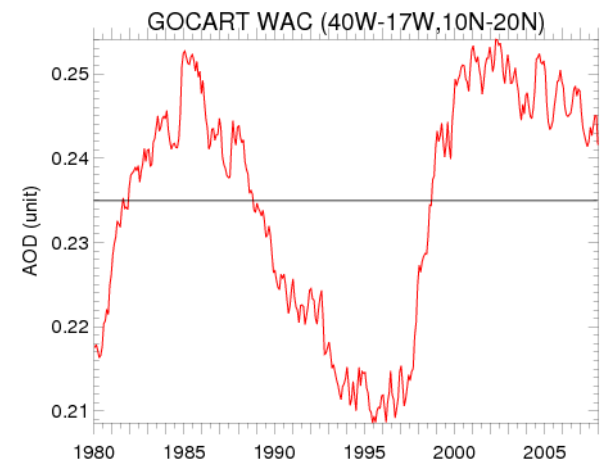
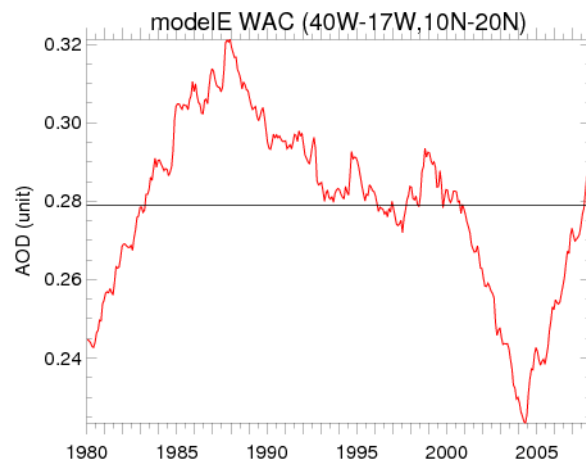
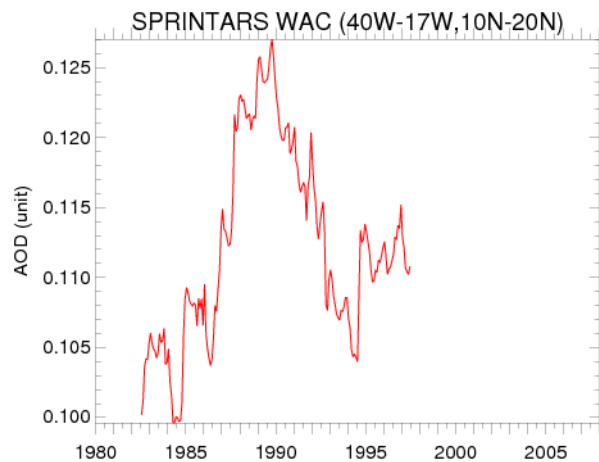
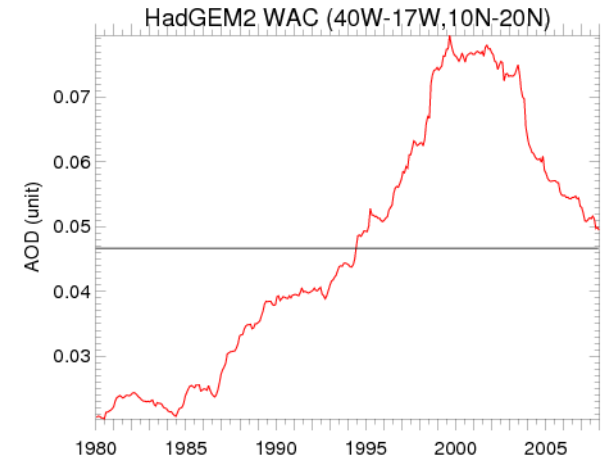
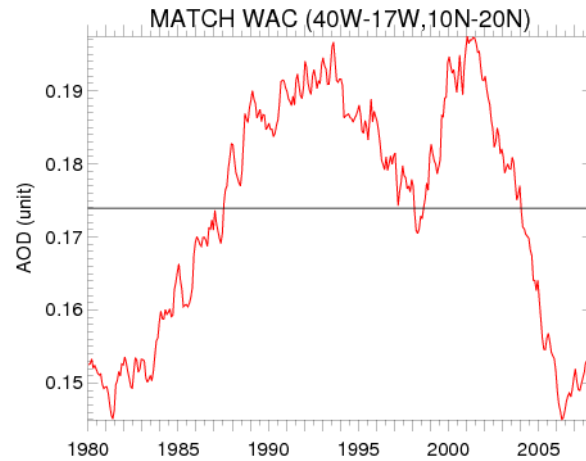
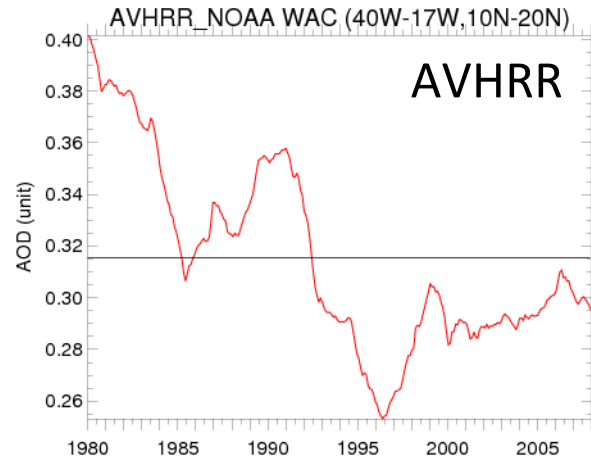
### 3. Dust trends over N Africa and tropical Atlantic



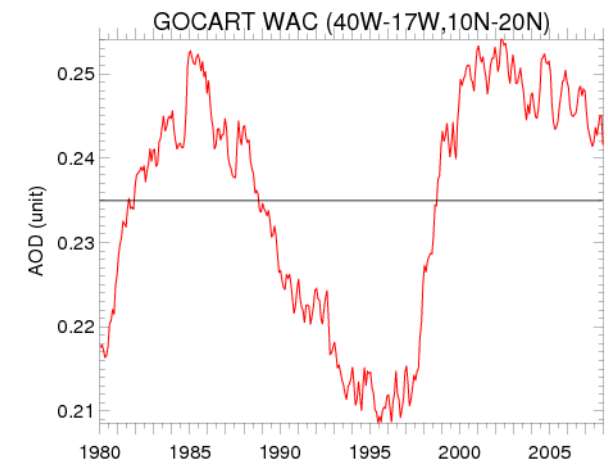
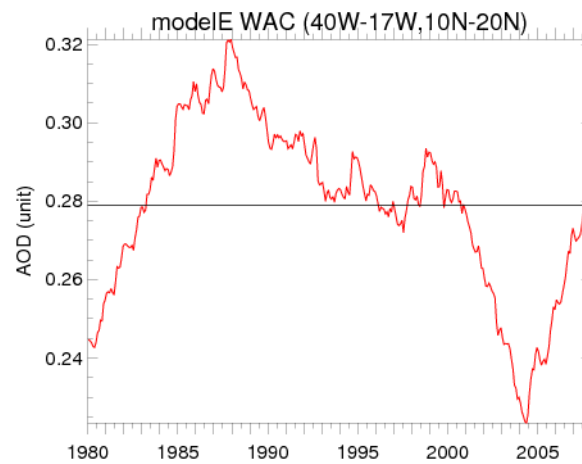
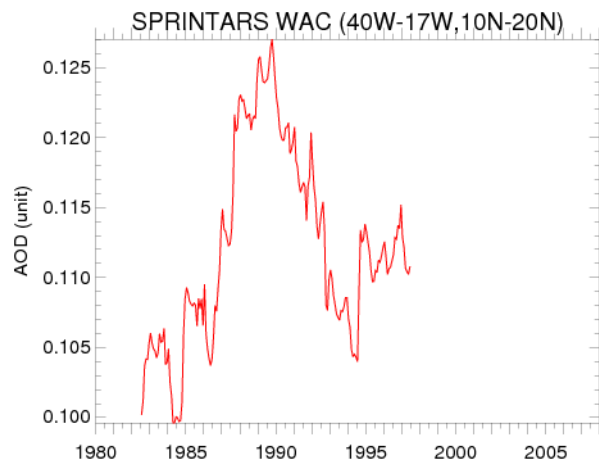
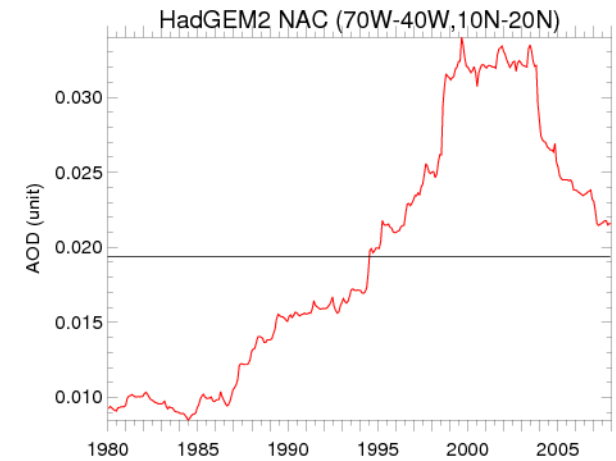
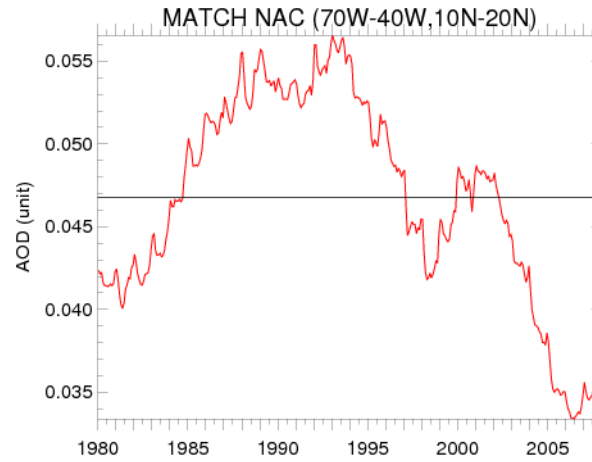
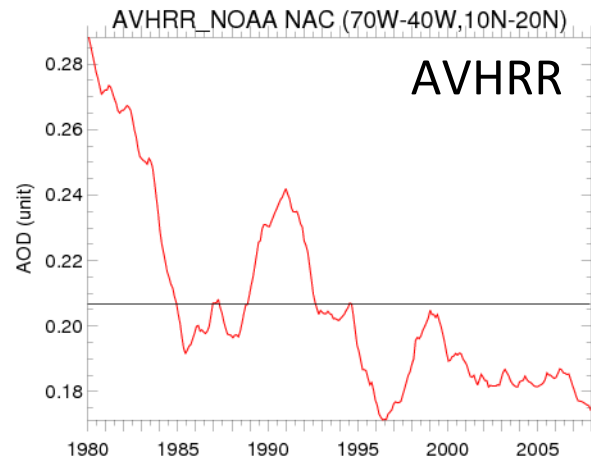
# Over region A (land)



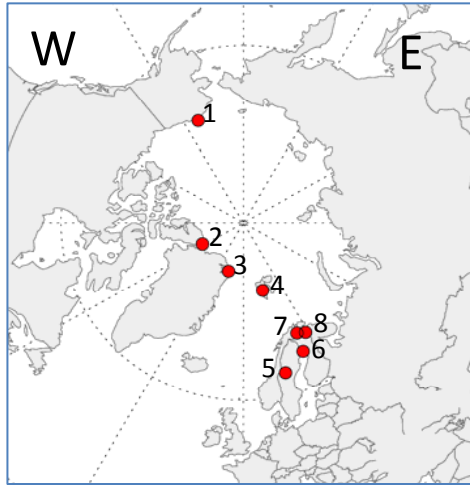
# Over region B (eastern tropical Atlantic)



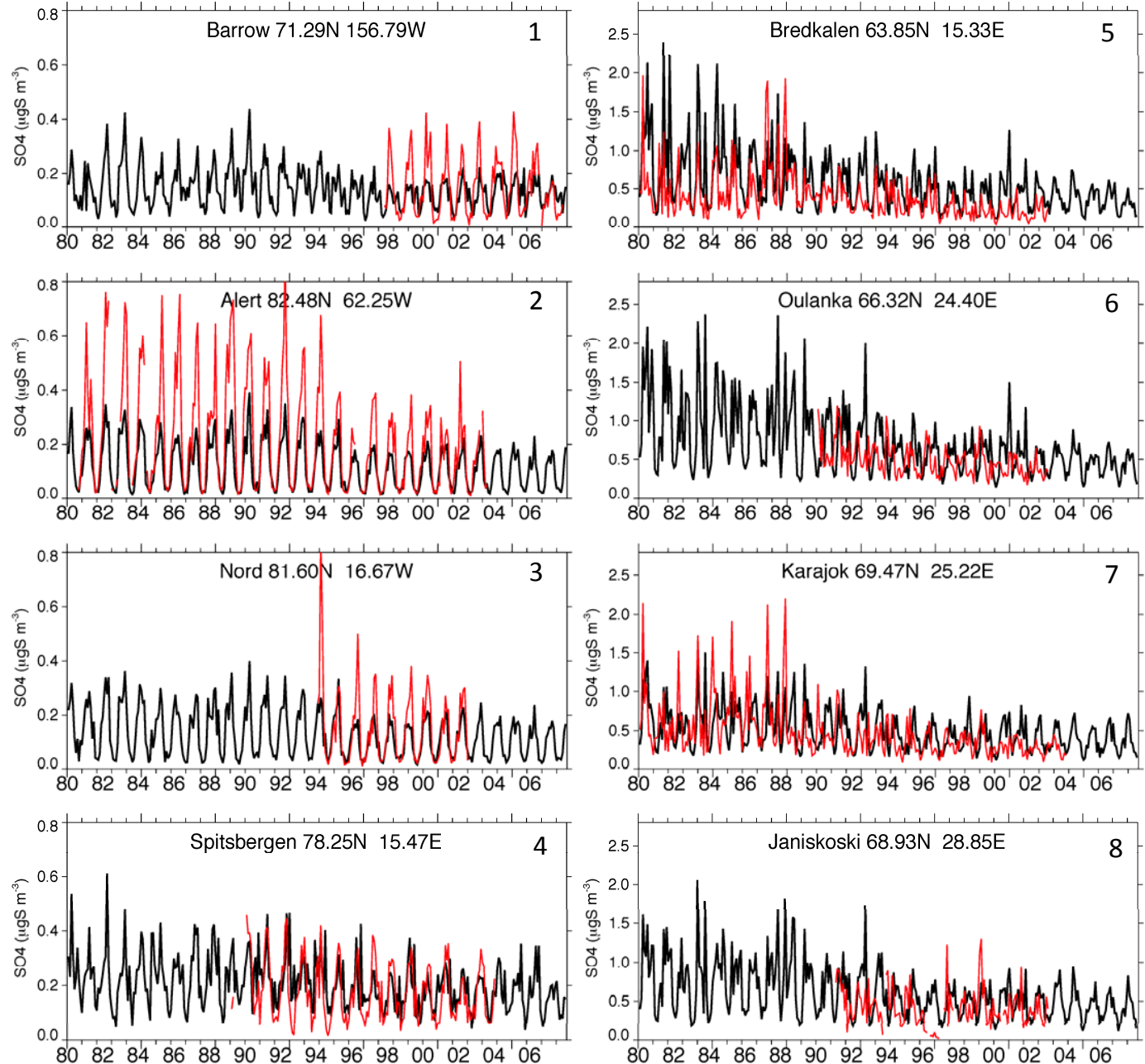
# Over region C (western tropical Atlantic)



# 4. Arctic Haze – sulfate surface concentrations



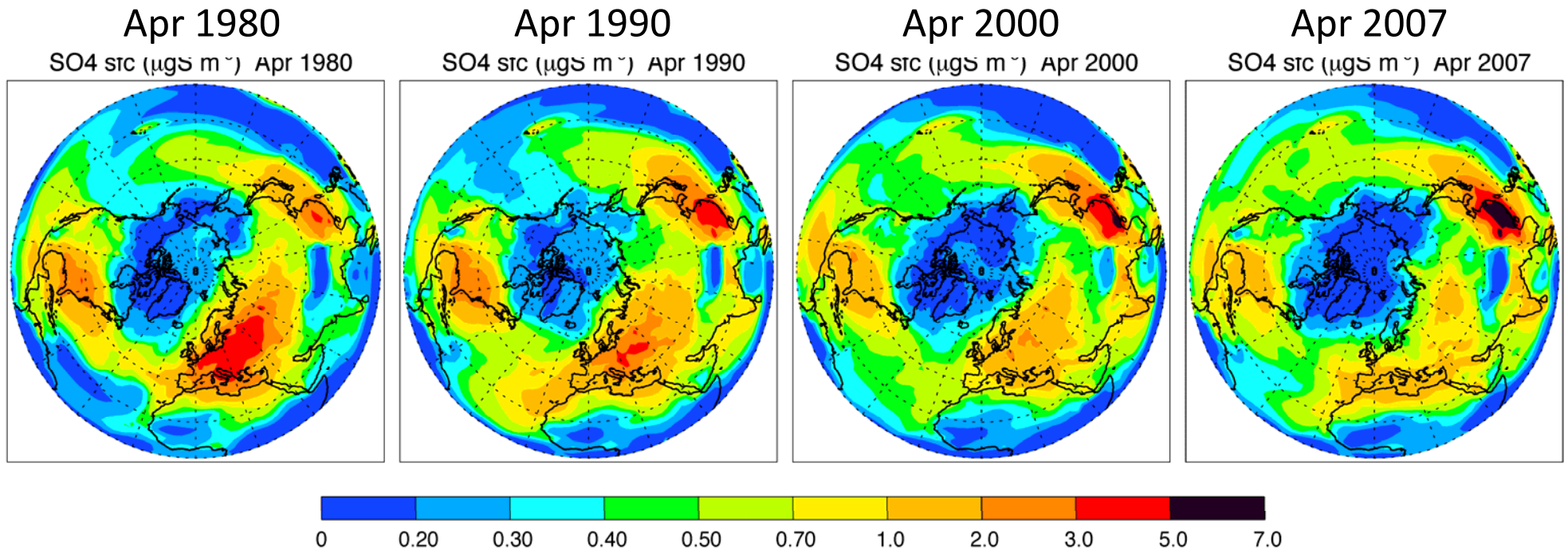
- Both observations and model simulation have shown a general decrease of sulfate concentration over the Arctic
- Over the eastern Arctic the magnitude of such decrease is much stronger than that over the western Arctic
- Over the western Arctic the sulfate concentration seems to have stopped decrease since the late 1990's
- Modeled concentration is about 2x lower than observations over the western Arctic



— Observations — GOCART

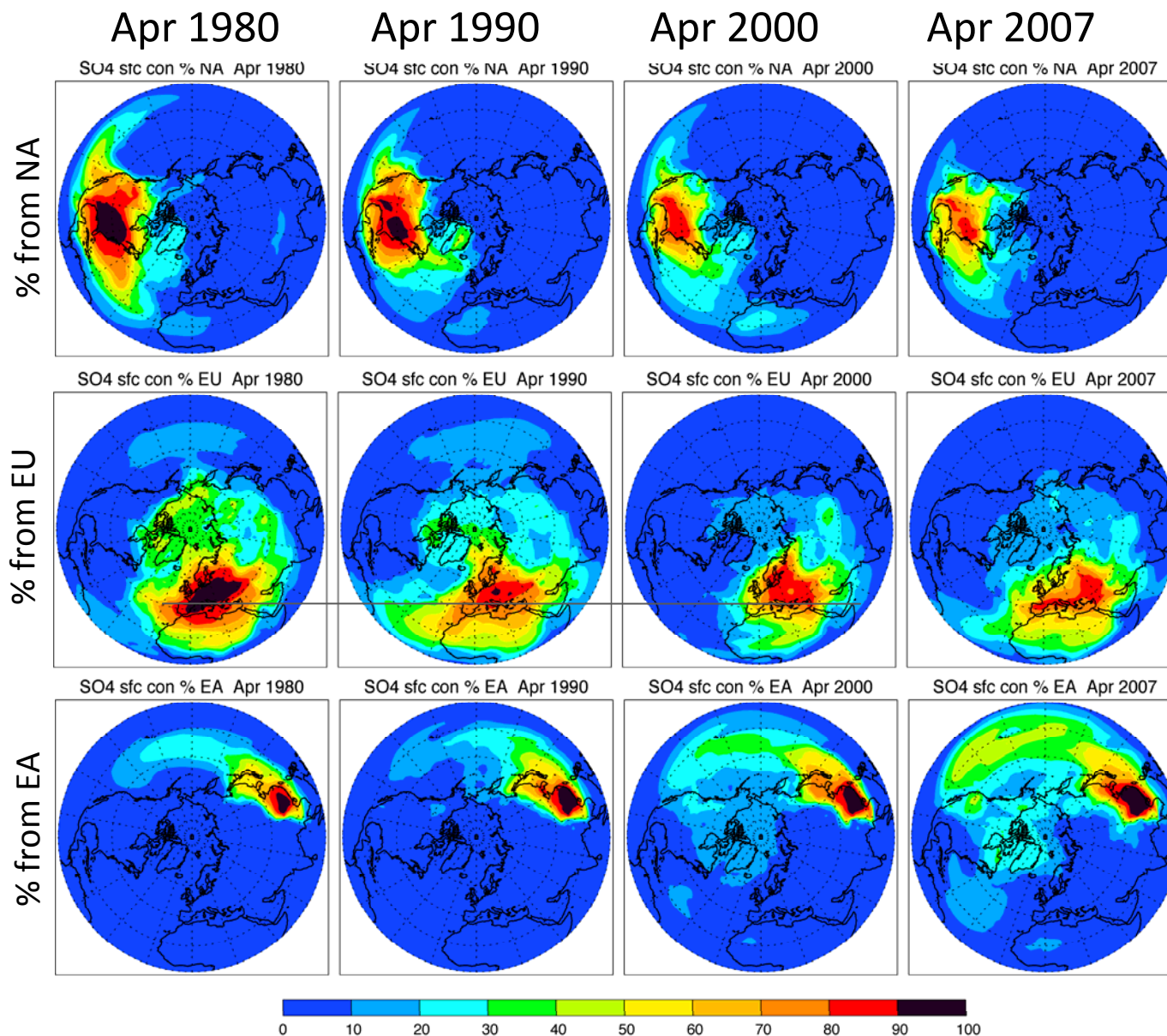


# Arctic haze – surface sulfate concentration



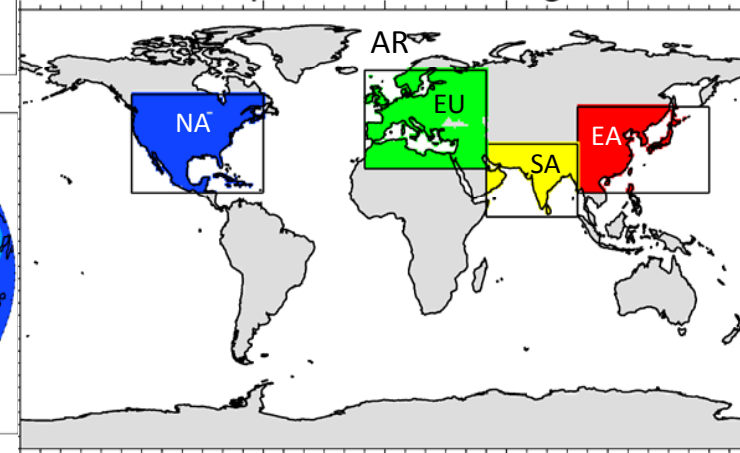
- Anthropogenic sources dominate the surface sulfate at the source regions
- Sulfate has been decreasing over NA and EU but increasing over EA and SA
- Concentrations in the Arctic are much lower than that in the mid latitudes and have been decreasing between 1980 and 2007

# Anthropogenic attributions (%) of surface sulfate from major source regions



- NA and EU anthropogenic sources are expected to be the major anthropogenic components over the western and eastern Arctic, respectively
- EA anthropogenic sources increasingly influence sulfate concentrations over the North Pacific and the western Arctic

Anthropogenic Source Regions



# 5. Stratospheric aerosol trends – volcanic or anthropogenic?

■ See my poster 

## Anthropogenic and volcanic contributions to the stratospheric aerosols

Mian Chin<sup>1</sup>, Qian Tan<sup>1,2</sup>, Thomas Diehl<sup>1,2</sup>, Nikolay Krotkov<sup>1</sup>, William Read<sup>3</sup>, Jean-Paul Vernier<sup>4</sup>, David Streets<sup>5</sup>  
<sup>1</sup>NASA Goddard Space Flight Center, U.S.A. <sup>2</sup>Universities Space Research Association, U.S.A. <sup>3</sup>NASA Jet Propulsion Laboratory, U.S.A.  
<sup>4</sup>NASA Langley Research Center, U.S.A. <sup>5</sup>DOE Argonne National Laboratory, U.S.A.

### Introduction

- $SO_2$  in the atmosphere mainly comes from fossil fuel combustion, which accounts for about 60-70% of total  $SO_2$  emissions with sources near the surface. The increase in anthropogenic emissions, largely from Asia, in the past decade may have contributed to the observed stratospheric aerosol trends (Hofmann et al., 2009, see Figure 1)
- Emissions of  $SO_2$  from volcanoes are on average 88-90% lower than those of anthropogenic sources globally, but strong eruptions can inject  $SO_2$  into the upper troposphere and stratosphere to form sulfate at high altitudes where residence time is much longer, making a disproportionately larger contribution to sulfate aerosol climate forcing
- This project attempts to assess the origin of stratospheric aerosols by using a global model GOCART to analyze the  $SO_2$  data from OMI and MLS, in combination with data from other EOS satellite sensors and in-situ measurements (results are preliminary)

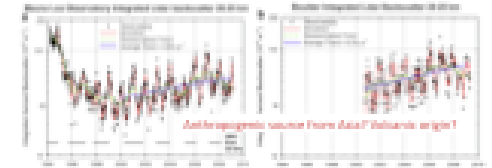


Figure 1. Stratospheric aerosol backscatter measured by ground-based lidar at (a) Mauna Loa, Hawaii and (b) Dobson, Colorado. From Hofmann et al., 2009.

### Anthropogenic $SO_2$ emissions, 2000-2007

- North America and Europe: Emission has been decreasing
- Asia: Emission has been increasing
- Global: Emission has been increasing, largely due to the increase in Asia

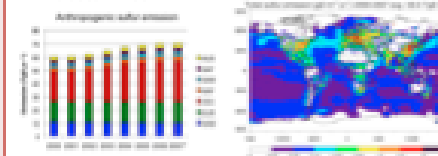


Figure 2. Anthropogenic sulfur emission from 2000 to 2007 used in the current GOCART model. NA=North America, EUR=Europe, ASIA=Asia, SAM=southern Africa, LAM=Latin America, SW=southern Africa, and AU=Oceania in the tropical South Pacific (emission data from Streets et al., 2004, and figure from Chinn et al., 2008).

### Volcanic $SO_2$ emissions, 2000-2007

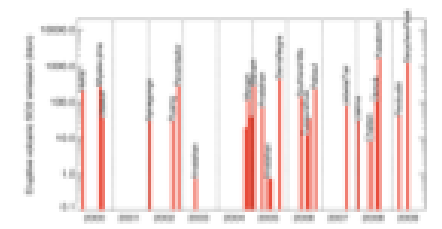


Figure 3.  $SO_2$  emission from major volcanoes from 2000 to 2007 with injection height above 10 km. Data source: NOAA, OMI, SRTM and trends reported in Bevilacqua (with compilation Thomas Diehl).

### Asian anthropogenic $SO_2$ from OMI and GOCART

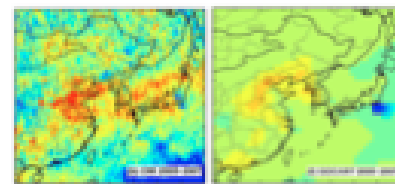


Figure 4. Difference in total  $SO_2$  column loading (in DU) over East Asia between 2000 and 2007 from (left) OMI and (right) GOCART (figure from Lu et al., 2008). The large negative trend in SE Japan reflects the difference in the Miyakejima volcanic emissions, which was active in 2000 but not in 2007.

### Soufrière Hills volcanic $SO_2$ from OMI, MLS, and GOCART

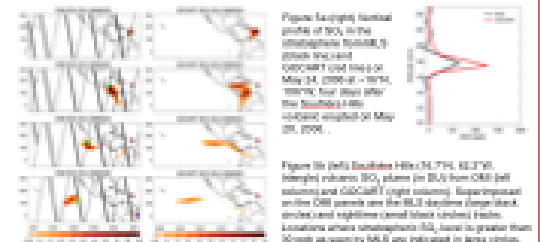


Figure 5 (top) Vertical profile of  $SO_2$  in the stratosphere from OMI, MLS and GOCART (top row) on May 14, 2000 and May 14, 2006, four days after the Soufrière Hills GOCART model on May 25, 2006.

Figure 5 (left) Soufrière Hills (19.7°N, 82.2°W) (right) volcanic  $SO_2$  (DU) from OMI (left column) and GOCART (right column). Superimposed OMI pixels are the MLS (blue large black circles) and rightmost small black circles. In situ locations above stratosphere 100 hPa (a greater than 10 gpa) as seen by MLS are indicated in large circles.

### Stratospheric aerosol extinction from GOCART, 2000-2007

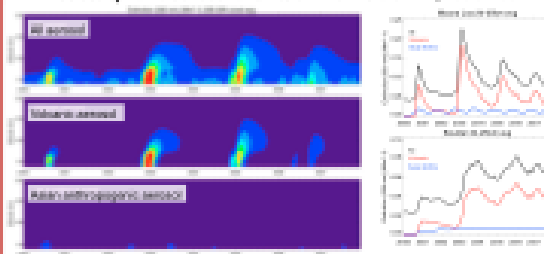


Figure 6a. GOCART calculated monthly average stratospheric aerosol 550 nm extinction profiles from 200 to 200 hPa. For all aerosols, visible volcanic aerosols, bottom: total anthropogenic aerosols.

Figure 6b. GOCART calculated monthly average stratospheric aerosol 550 nm extinction profiles over (left) Asia and (right) Soufrière (left). Total (left), volcanic (middle), and Asian anthropogenic (right).

### Remarks

- Preliminary model results indicate that volcanic aerosols is the dominant aerosol type in the stratosphere during 2000 to 2007, a period lacking of major volcanic eruptions
- Asian anthropogenic aerosols, although having been increasing during this period, plays only minor roles in the stratosphere. It is much more important in the lower troposphere
- We are continuing improving model simulations to more accurately estimate the volcanic emissions and injection height and stratospheric residence time
- Other model experiments are being conducted

**Acknowledgement.** This work is supported by NASA MAP and Aura Program.