Air Pollution as a Climate Forcing- Honolulu, Hawaii
April 4-6, 2005

Regional Climate Impacts of Air Pollutants

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What I am looking for: Whether confidence in regional effects - aerosol effects on precipitation- has improved.

Common Air Pollutants

In the past,US EPA set national air quality standards for **six principal air pollutants:**

Nitrogen dioxide (NO_2),

Ozone (O_3),

Sulfur dioxide (SO_2),

Particulate matter (PM),

Carbon monoxide (CO), and

Lead (Pb).

Image from
www.enviropedia.org.uk

Particulate matter over China and India

Regional measurements of **OC/BC** over 4 cities in PDRC (Cao et al., 2004.)

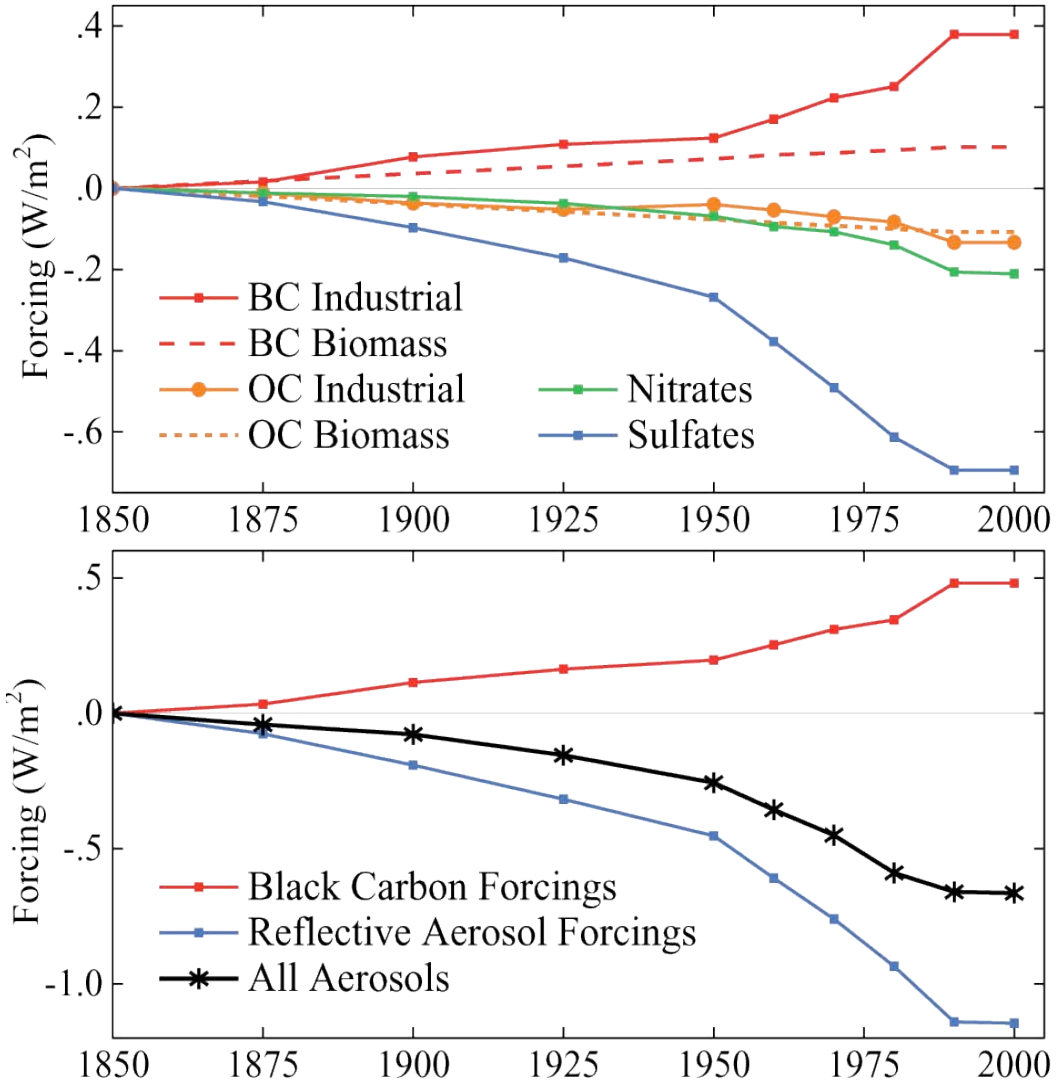
- ~ 1/3 of PM 2.5/10 mass were **carbonaceous**.
  PM2.5: **OC = 9.2** **and** **BC = 4.1** mg m^{-3}
  PM10 : **OC =12.3** **and** **BC = 5.2** mg m^{-3}
- No strong seasonal fluctuations in OC and BC.
- Motor vehicle emissions === major source.

Over India: Particulate matter more important than NO_x or SO_2.

- **Biofuels/fossil fuel combustion major contributor to deteriorating air quality.** (Mitra and Sharma, 2002).
- **BC source ratio (biofuel/total) ~ 44% in India compared to 15% globally** (Venkataraman et al. 2005).

Why focus on Black Carbon Aerosols?

Time dependent effective aerosol forcings determined from model (GISS) simulations.



(From Hansen et al. 2005)

Why focus on Black Carbon Aerosols?

- Although organic (OC) and black carbon (BC) have same sources, optical properties are different.

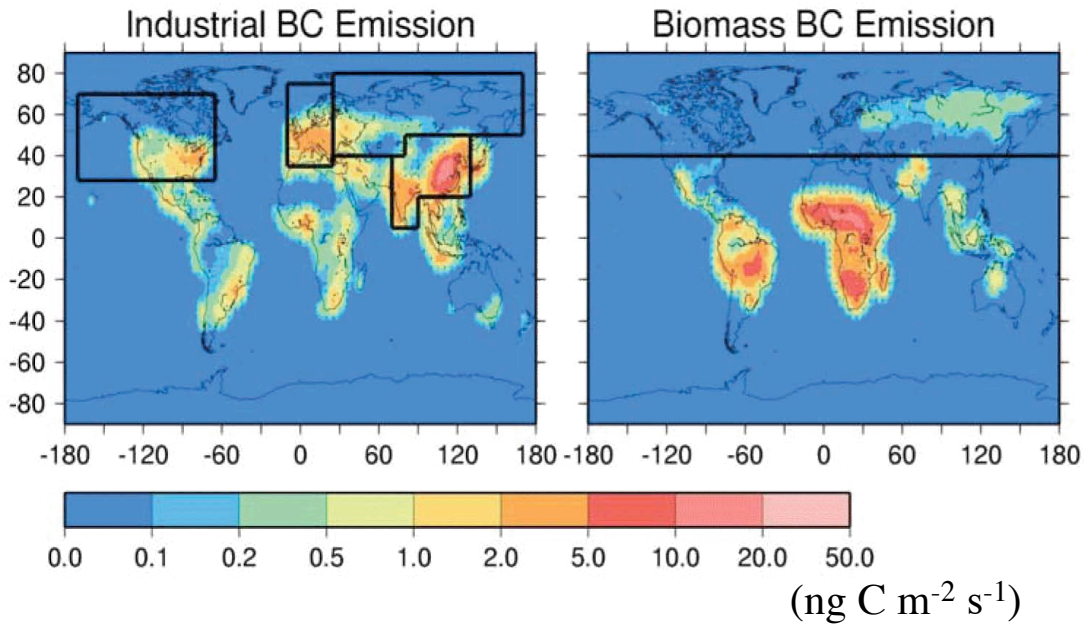
BC :	Real: 1.56 to 1.60	Imaginary: **0.48 to 0.53**
OC :	Real: 1.5	Imaginary: **0.029 to 0.005**

- Regional climate effects--due to spatial heterogeneity in aerosols.

BC distributions in the GISS GCM (Koch and Hansen 2005).

Industrial: Bond et al. (2004).

Biomass: Cooke and Wilson (1996).



Black Carbon Sources

Black carbon is a product of **incomplete combustion** from:

Industrial emissions, Diesel fuel,

Burning of wood, biofuels, field residue, Outdoor biomass burning etc.

Amounts: **Industrial = 6.6/5.2/6.5** Tg/yr

Biomass = 5.6/6.0/11 Tg/yr

(**Chuang et al. 2002**; **Koch, 2001**; **Chin, 2002**)



Images: http://www.asthmacure.com, NASA GSFC

Shenyang, China: Major Industrial City

Snow cover change between urban and rural areas

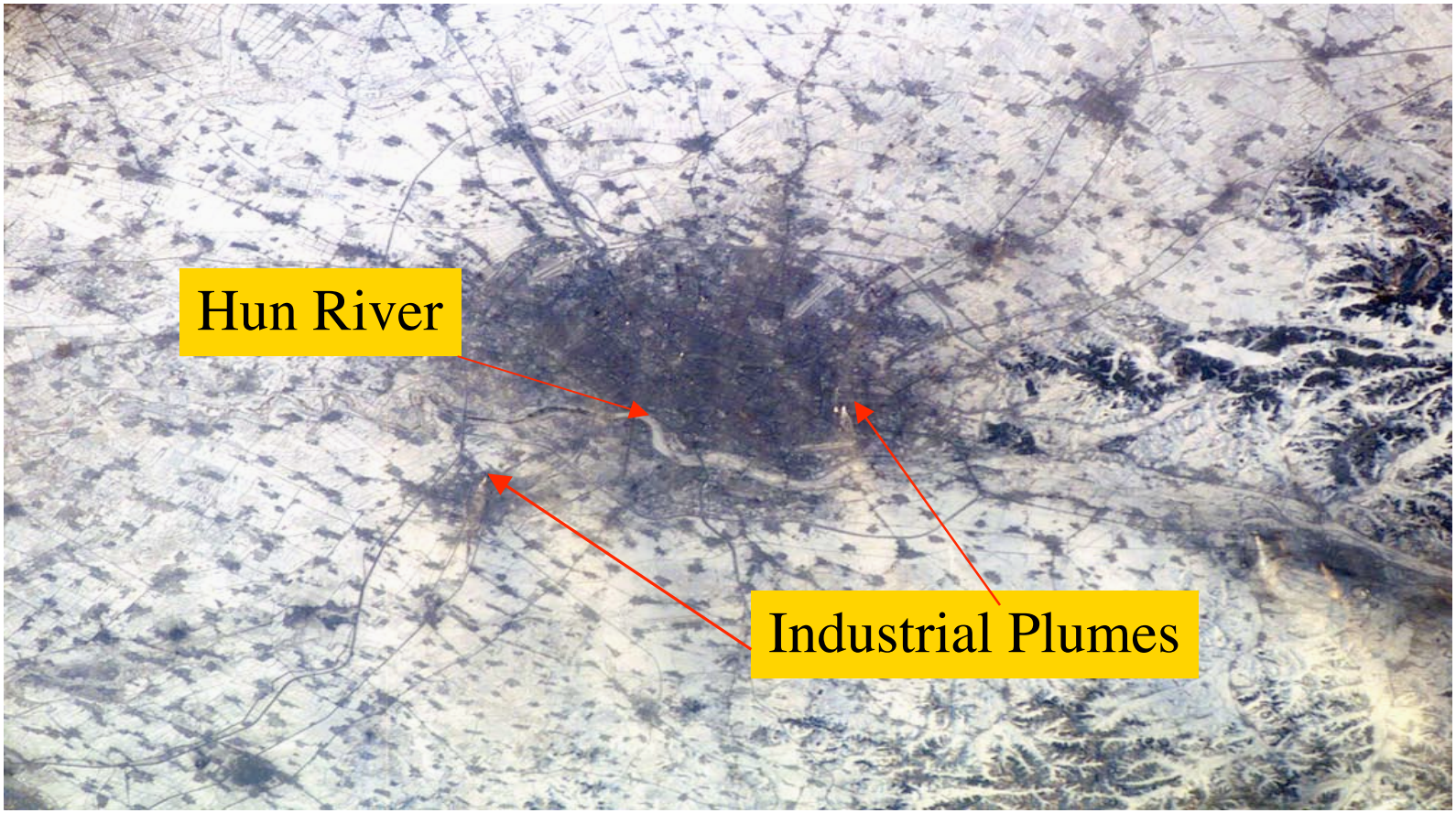


Image courtesy of the Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov)

Astronaut photograph ISS010-E-13807, acquired January 18, 2005

Regional climate effects over China

- Most significant **effect of BC is shift in the regional precipitation**
  - shift of centers along ITCZ and SPCZ (**Wang, 2003**)
- Change in snow depth for the Northern Hemisphere.

- Over eastern China (1955-2000), for **daily mean summer temperatures**
  ⇓ trend in the freq. of low extremes and
  ⇑ trend for high extremes (**Gong et al. 2004**).

- Largest ⇓ in max temp. for Yangtze river valley also has ⇑ in precipitation (correlated to **anomalies in the NW Pacific subtropical high** + …).
- Precipitation trends stronger since the mid 1980s (**Zhai and Pan, 2003**).

- Other studies support the ⇑ precipitation trends over the Yangtze rive valley, with ⇓ trends over the north and north-east China (1951-2002) (**Xu, 2001**, **Gemmer et al. 2004**).

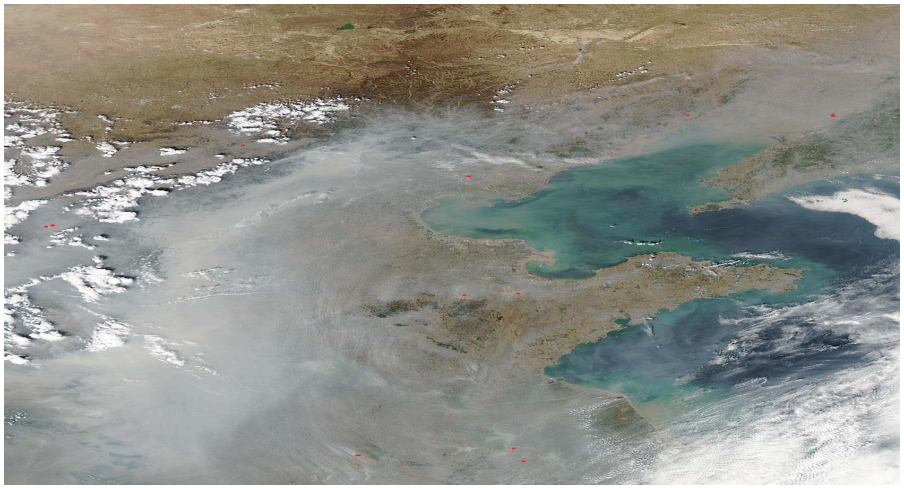
- **Seasonal variations** in satellite retrieved **cloud droplet effective sizes** that are associated with **precipitation changes** over east Asia. (**Kawamoto & Nakajima, 2003**).

Regional climate effects

- Surface humidity index over China (1951-1998) (Ma and Fu, 2003)
  Drought over central N. China mainly from a decrease in precipitation and partly due to increased evaporation.

- Surface observation of solar radiation (Li et al. 1998 and Luo et al. 2000):
  Significant reduction (~10%) in average surface solar insolation (direct and diffuse) over most of China from **1970 to 1990**.

- **Sunshine duration in Taiwan** (Liu et al. 2002):
  General reduction after 1970. 1995-1999 five-year average sunshine hours ~16% below the mean value of 1898-1999.
  May be attributed to increase in regional clouds and /or cloud albedo.

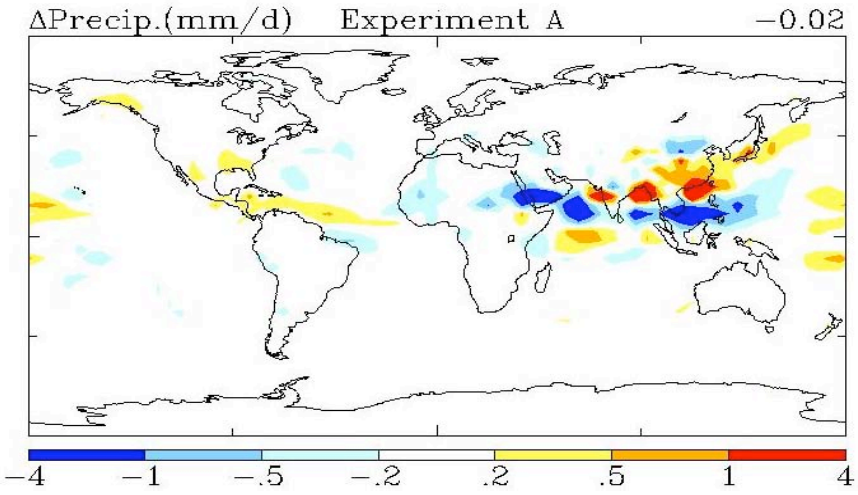


Source: MODIS Image Gallery

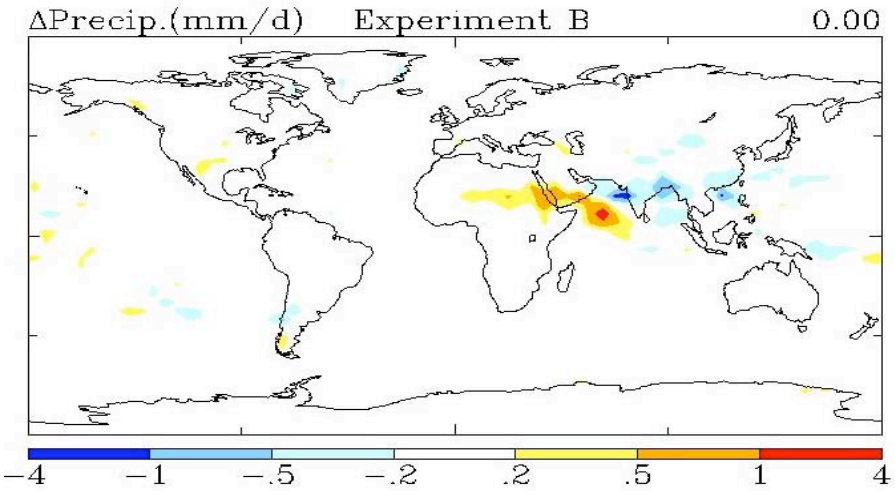
Regional precipitation trends

- We examine the mid-summer precipitation trends in China "**North Drought-South Flooding**". (Menon, Hansen, Nazarenko and Luo, 2002)
- Changes in temperature gradients from aerosol forcing gives rise to the large scale precipitation changes.
- **BC absorption ⇒ lower level heating**, change in vertical motions, circulation, cloud cover and **rainfall**.
  - Aerosol **vertical distribution** is important (Menon, 2004).

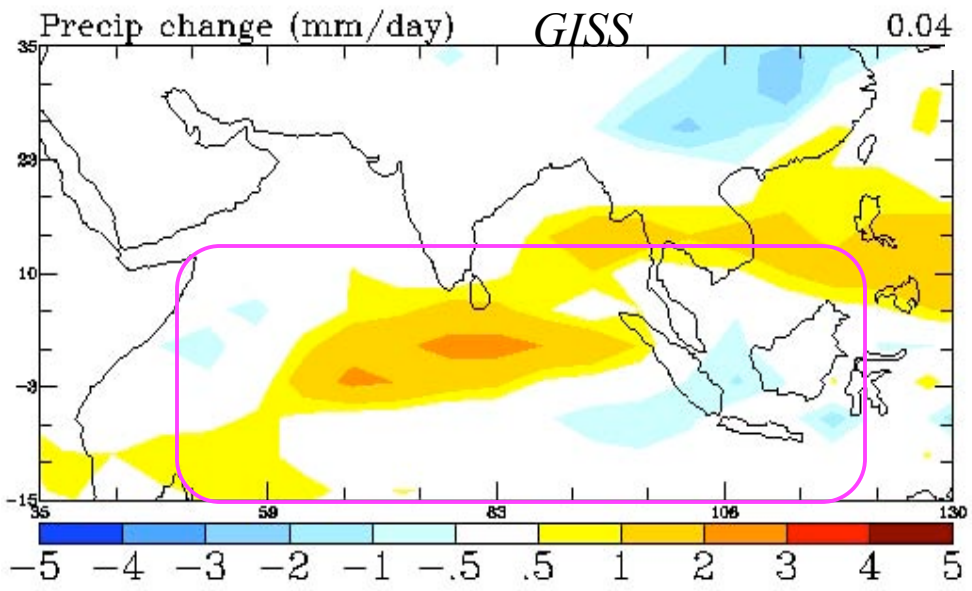
With black carbon



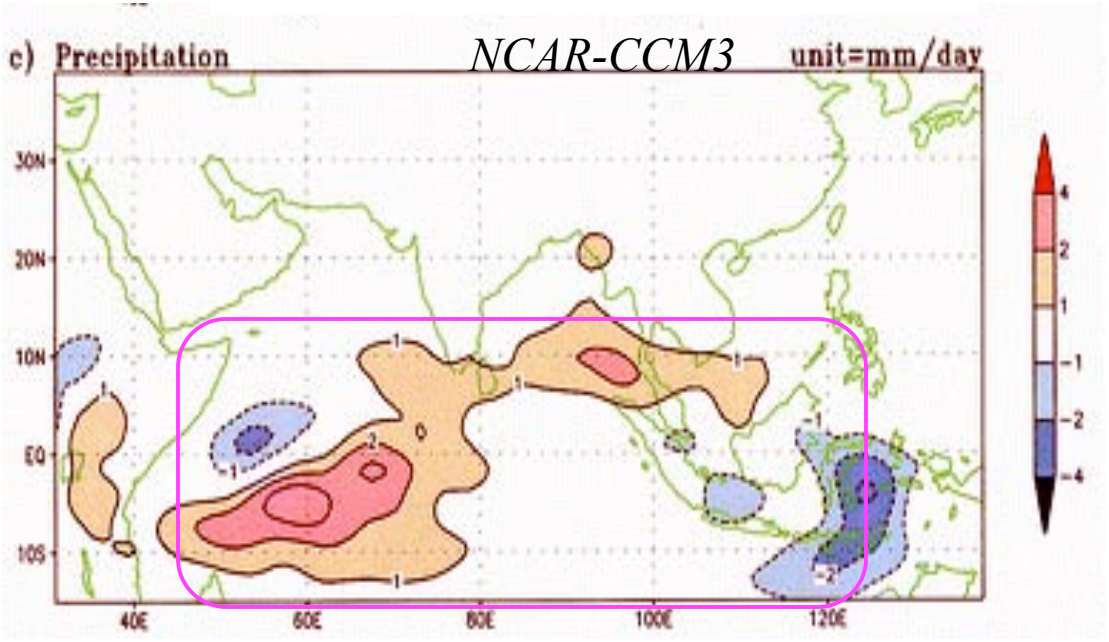
Without black carbon



Precipitation change - Indian Ocean region (Jan-Apr)



Similar shifts in precipitation pattern from absorbing aerosols found in the Indian Ocean by Ramanthan et al. (2001) during INDOEX.



Ramanathan et al. 2001, JGR; Chung et al. 2002, J. Clim.

Regional climate effects

- **Climate sensitivity of BC direct forcing ~ 0.6 K W^{-1} m^2**

- Annual mean radiative forcing over China :
  Anthropogenic BC: 5.0 W m^{-2}
  Anthropogenic O_3: 0.5 W m^{-2}
  25 ppm increase in CO_2: 0.1 W m^{-2}

- **Water vapour mixing ratio increases in low latitudes and during summer** due to BC forcing effects.

- **Changes to precipitation occurs over central Pacific away from BC sources:**
  Enhanced interhemispheric temperture difference---- change in zonal meridonial circulation and convection in tropics.
  Precipitation and convective cloud cover correspondence.

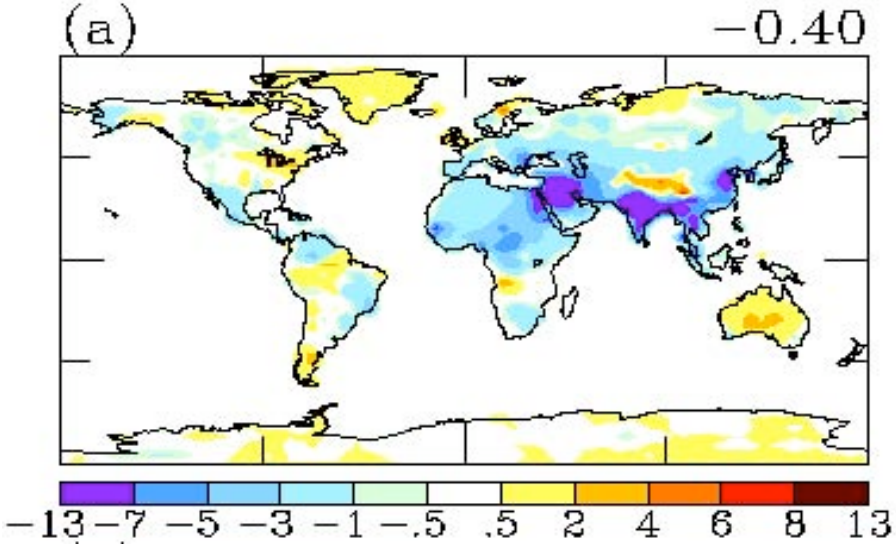
(Chung and Seinfeld, 2005, JGR)

- Observational records for latter half of 20th century over China (Che et al. 2005):
  Global radiation (-4.5 W m^{-2} per decade)
  Direct radiation (-6.6. W m^{-2} per decade)
  Clearness index (-1.1% per decade)
  Sunshine duration (-1.28% per decade)

Surface radiative forcing from Aerosols

- **Worldwide reduction in land surface radiation of ~ 3-6 W m^{-2} over the last several decades (1960 to 2000).**

Linear trend in net surface radiation from the GISS GCM (1960-2002)

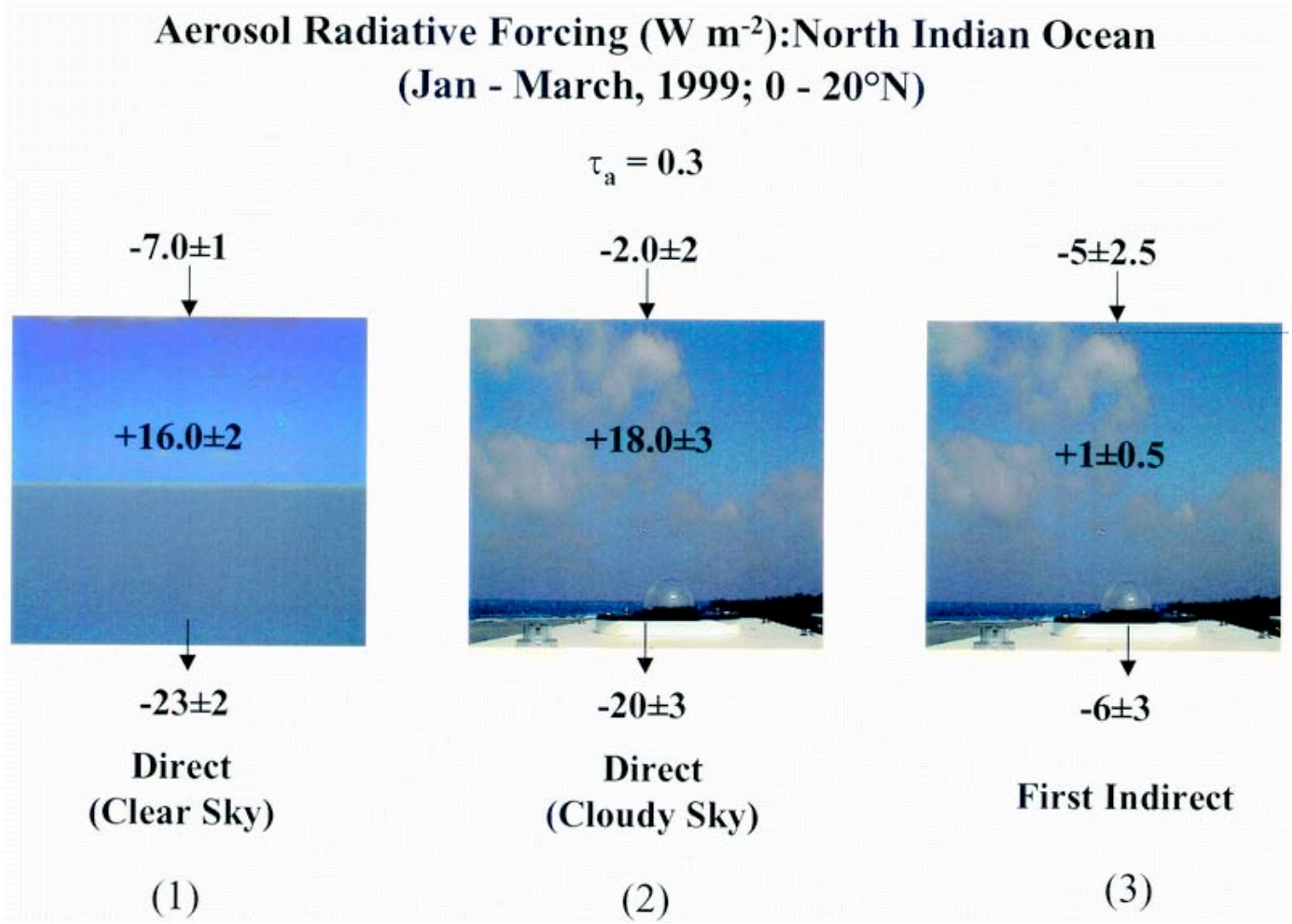


Results from the model show:
- decrease in absorbed solar radiation,
- increase in surface temperature,

~ to observations.

(Nazarenko and Menon, 2005)

Radiative forcing from Aerosols

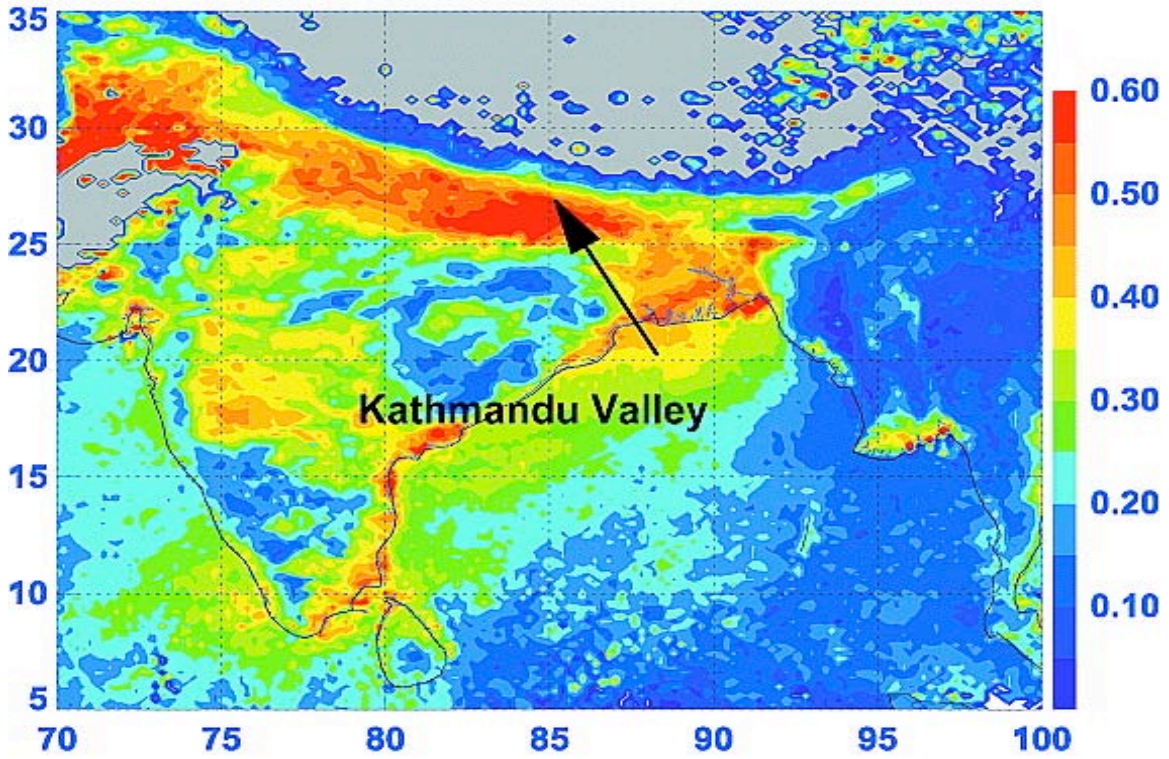


(Ramanthan et al. 2001)

Radiative forcing from Aerosols Over Himalayas

Aerosol visible optical depths ~ 0.6 and
aerosol single scattering albedo ~ 0.78.
⇒ significant absorbing aerosols

Inferred short wave atmospheric forcing ~ 25 Wm^{-2}.
Based on measurements (Atmospheric Brown Cloud project).



Aerosol optical depth from satellite data (MODIS) for Dec 2002.

(Ramana et al. 2004)

Long-range climate effects of Aerosols

Based on measurements during the inter-monsoon period over India (South-west coast) (Moorthy et al. 2005).

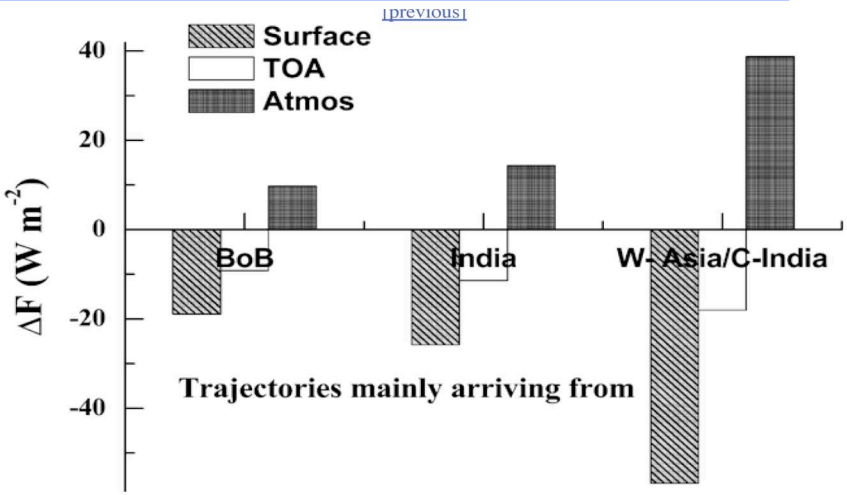


Table 2. Regional Industrial Emissions and Contribution to Arctic τ

Region	Sulfur Emissions, %[a]	Sulfate Arctic τ, %	BC Emissions, %[a]	BC Arctic τ, %
South Asia	33	17	44	30
Europe	14	14	10	14
North America	16	13	8	11
Russia	10	24	4	12

[a]Percent of global industrial emissions.

(Koch and Hansen, 2005)

Black Carbon, Ozone and Dust

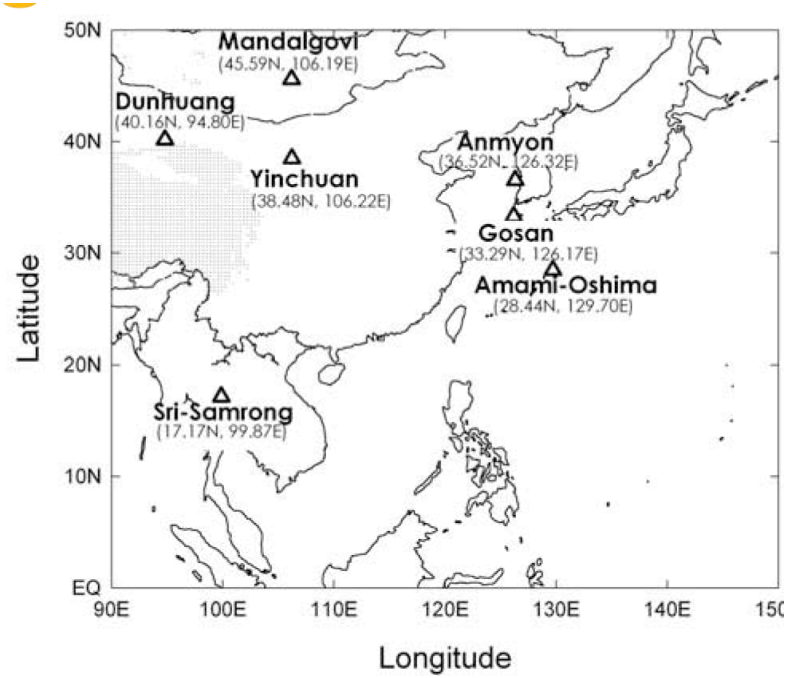
- Every **1 mg m^{-3} increase in BC causes a 3.5 mg m^{-3} reduction in O_3**
  -----Surface reactions on soot. (Latha and Badarinath, 2004.)
- High VOC to NOx ratios (two-stroke engines) inhibit photochemical smog.

Based on Jan 2004 data over Hyderabad, India.

VOC: Volatile Organic compounds; NOx: Nitrogen oxide radicals

Enhanced atmospheric heating effects for dust mixed with soot from industrial/urban areas of China (Kim et al. 2005).
----- SKYNET measurements.

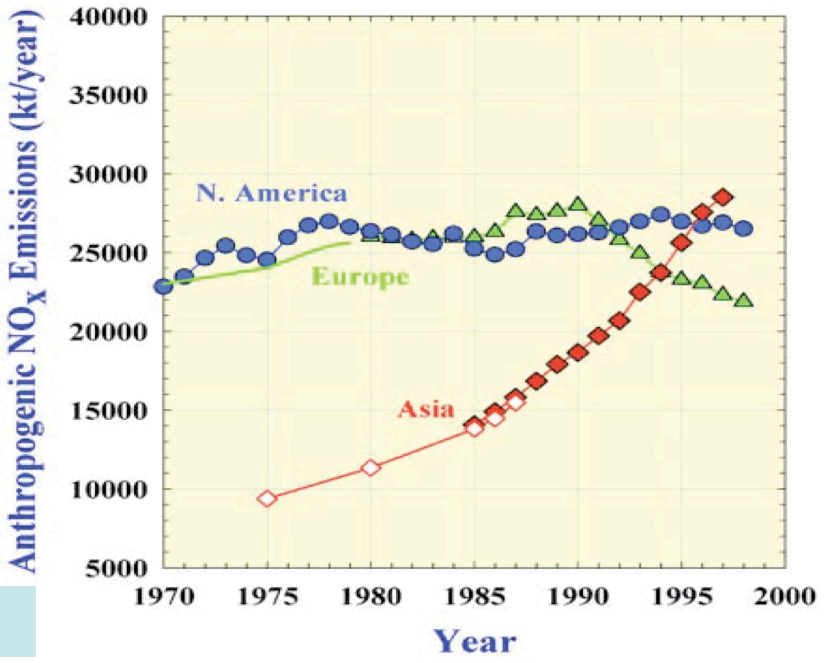
Indian pollutants transported to China (25-30N), Chinese pollutants from North and NE China pollute Korea and Japan (Wu and Fu, 2005)



Cause for concern

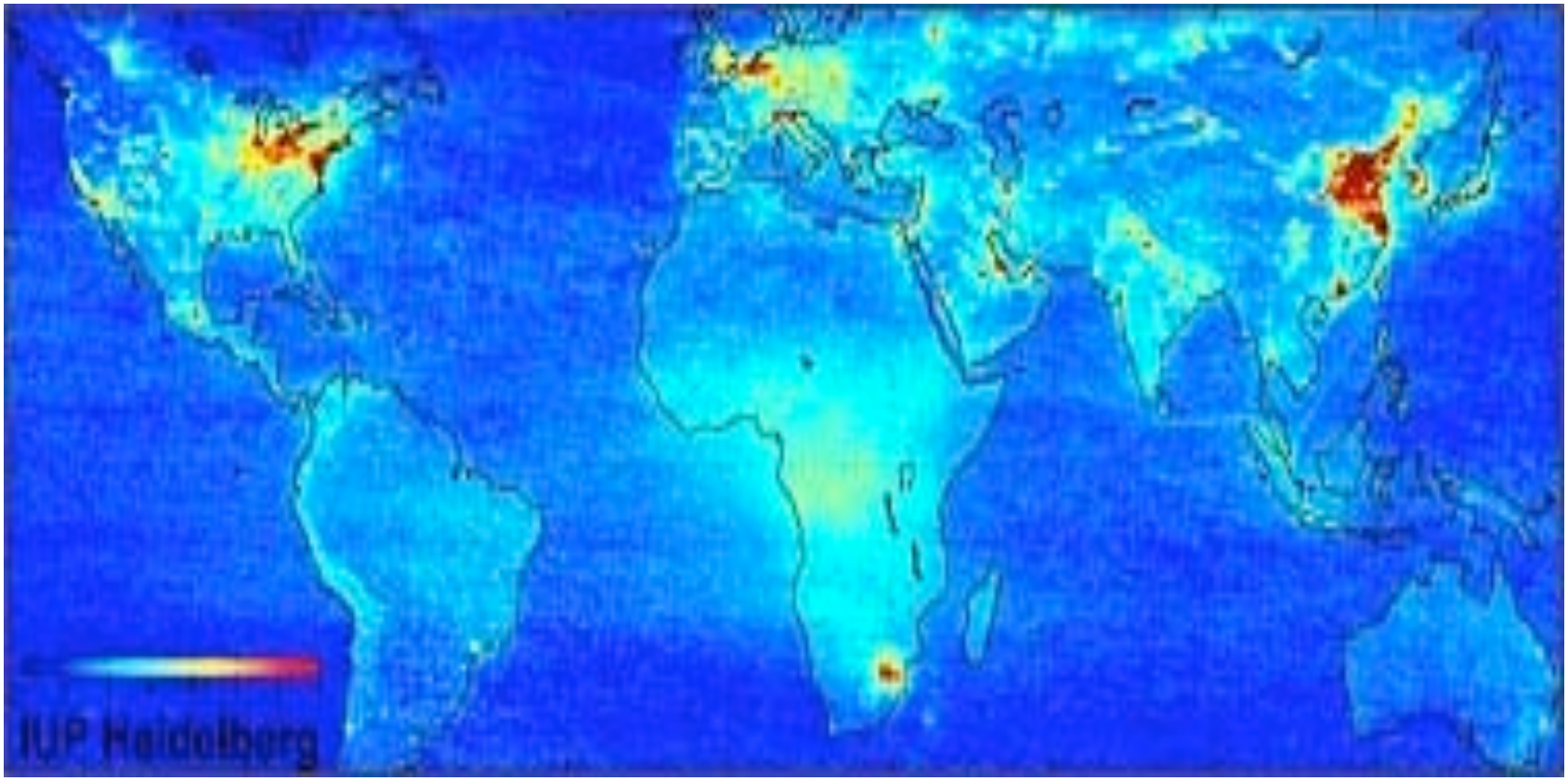
- 1997 annual sulfur emission(Streets et al. 2000)
  East Asia: 27.8 Tg/yr
  China : 25 Tg/yr
- SO_2 for A1B scenario in 2020 exceeds objectives -- China and Korea.
  ---- Sulfur related envtl. /health problems will grow in Asia (Pham et al. 2005).
- 2000 inventory of air pollutants (Streets et al. 2002)
  BC emissions in China -- fossil and bio-fuel : 1.05 and 1.17 Tg/yr
  Japan : 0.053 Tg/yr.

- NOx emissions are rising in Asia.



Akimoto (2003), Image source from D. Alles

Nitrogen dioxide – Envisat observations



High vertical columns of NO_2 --major cities across N. America, NE China, Europe, Mexico City, S, Africa coal-fired power plants.

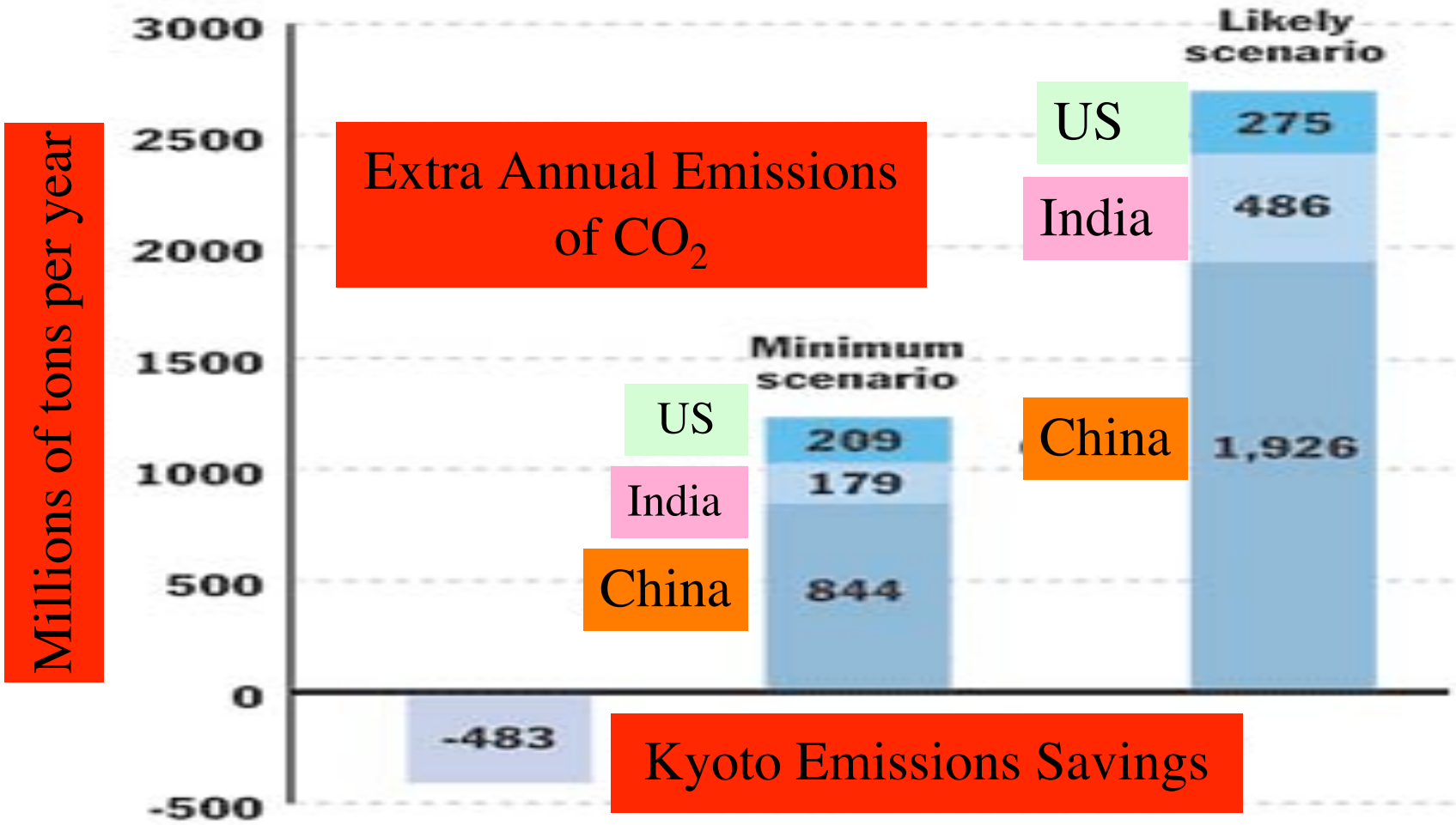
SE Asia and Africa: NO_2 from biomass.

Ship tracks : Red Sea, Indian Ocean

Based on 18 months of data.

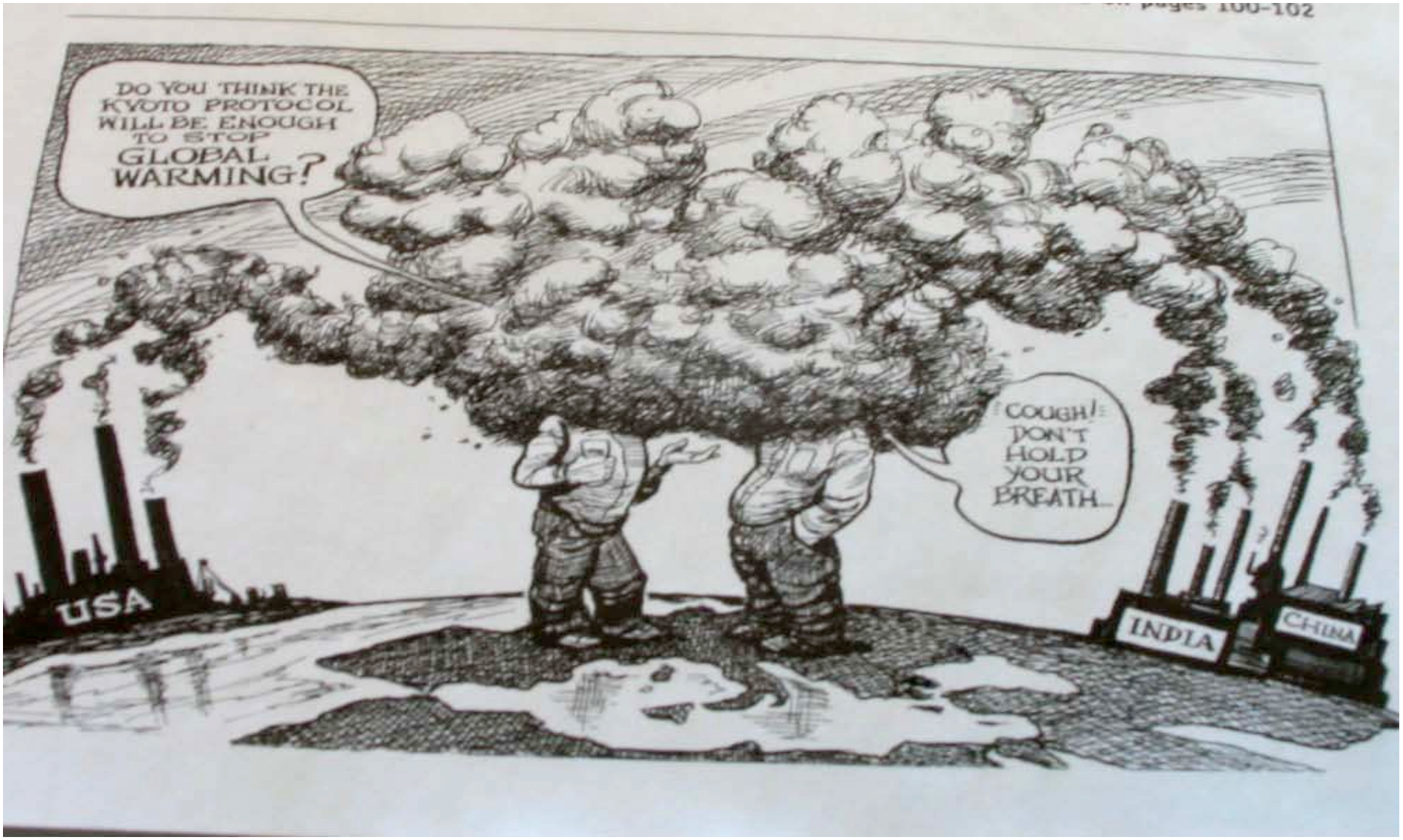
Future of Coal

Building of 850 new coal power plants



Source: Mark Clayton, Christian Science Monitor, Dec 23, 2004

Future



Source: The Economist, Feb 19-25, 2005