Carbonaceous Aerosols and their Climate Impacts

The Effect of Aerosols on the Asian Monsoon

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EAS 8802

Outline

- Importance
- Background/Definitions
- Past and Current Studies
- Summary

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Asian Monsoon

- South Asian Monsoon
  - Indian subcontinent and surrounding regions
- East Asian Monsoon
  - Southern China, Korea, Japan

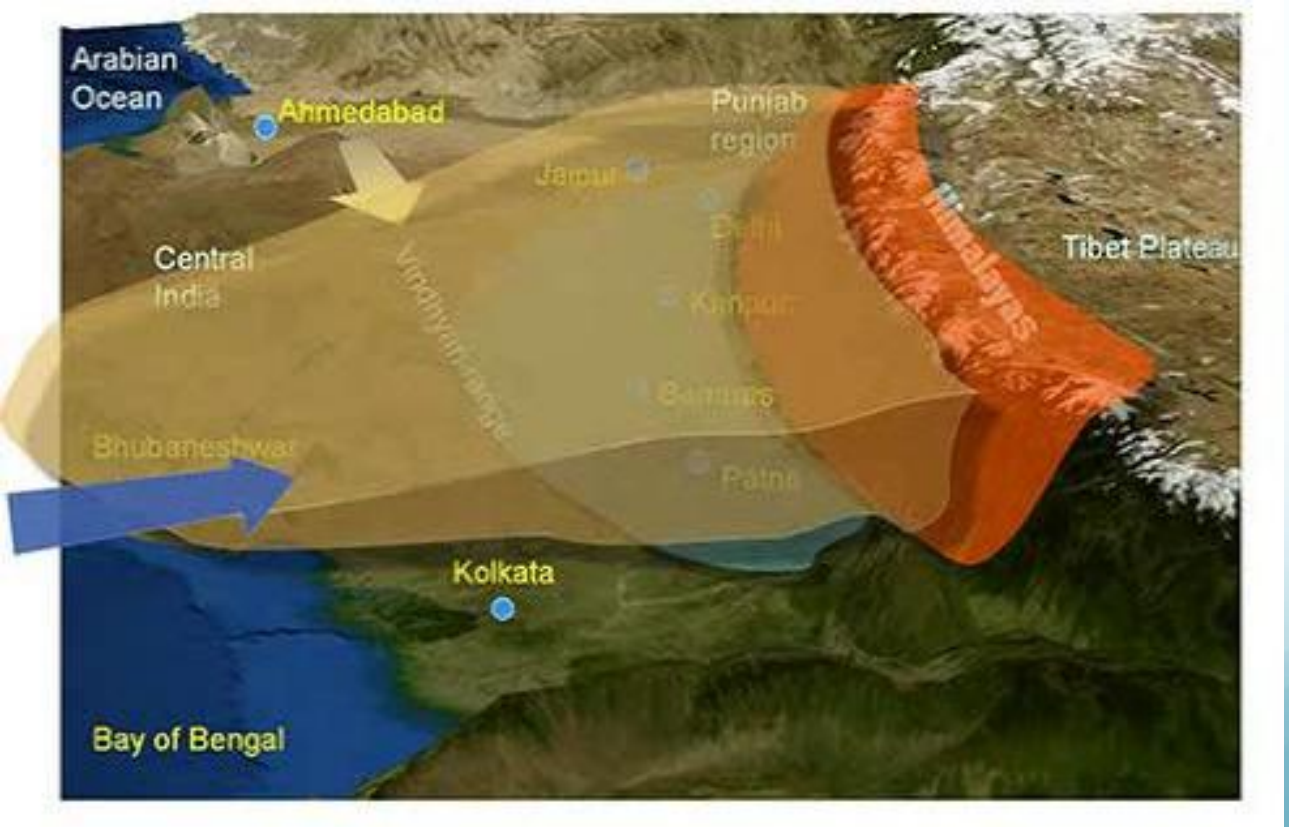
http://www.lonelyplanet.com/maps/asia/

Asian Monsoon (cont'd)

- Driven by the land-sea temperature contrast, orographic lifting, and large scale dynamics
  - Heating of desert in summertime leads to a low pressure system in northern India
  - Moist air from the Indian Ocean flows in at low levels
  - Air runs into the Himalayas (or Ghats) and is forced to rise
  - Precipitation!

Black Carbon

- Formed both naturally and anthropogenically through the incomplete combustion of fossil fuels, biofuels, and biomass
- Absorbs sunlight and warms the atmosphere



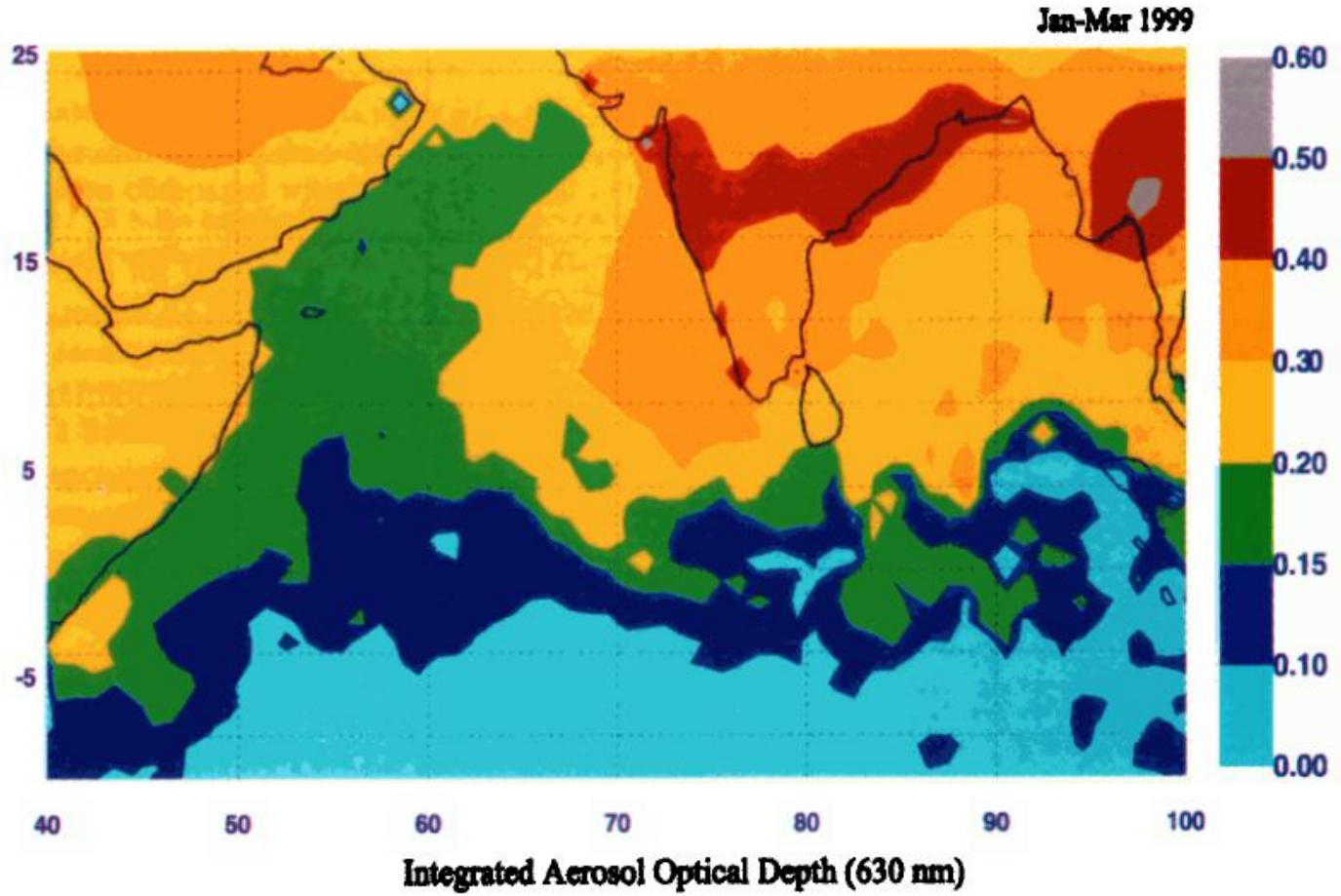
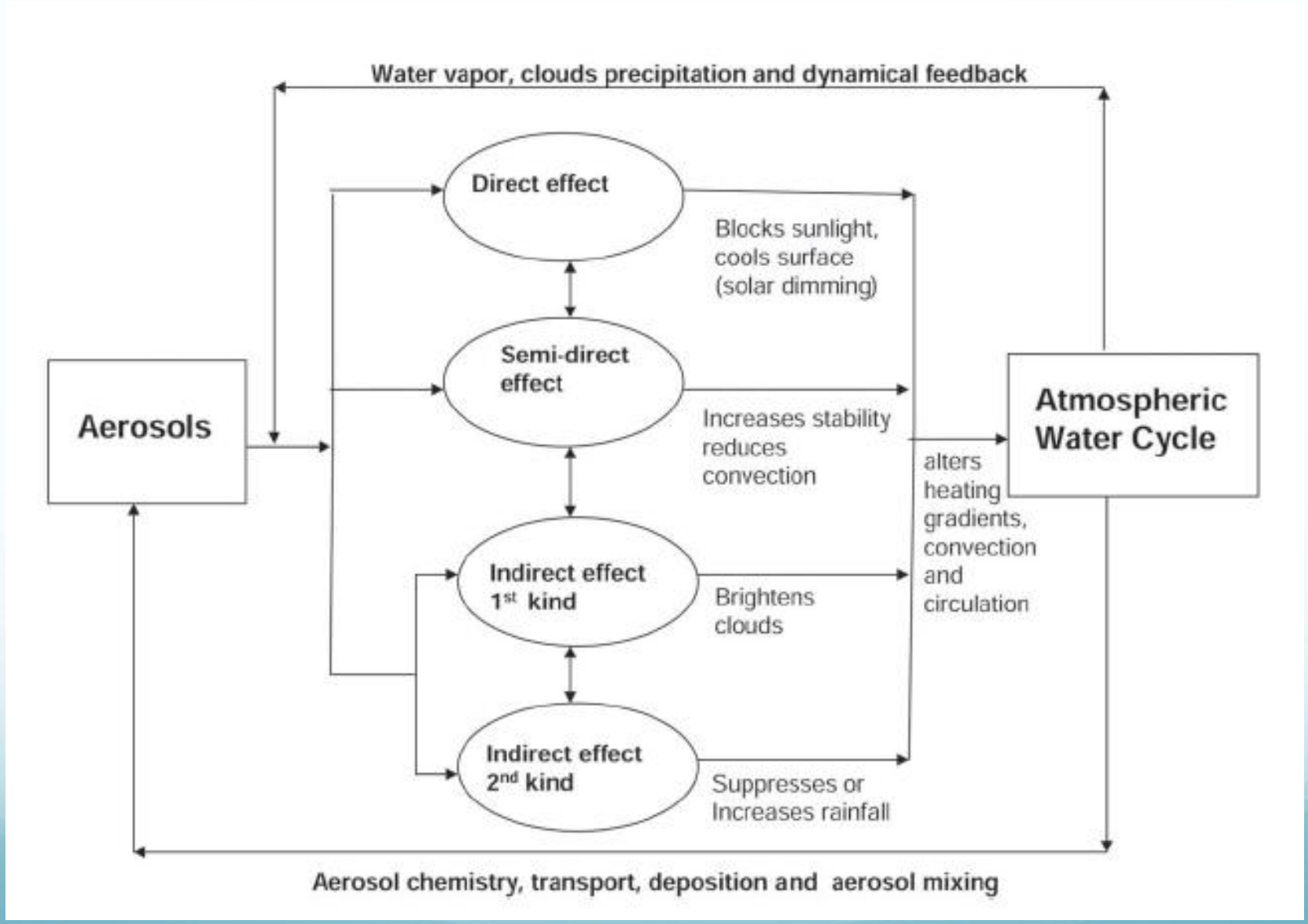


Plate 5. The regional map of aerosol visible optical depth τ_a. The τ_a values over ocean are retrieved from AVHRR data [*Rajeev et al.*, 2000] and over land are estimated using a 4-D assimilation model [*Collins et al.*, 2001]. The figure illustrates the north-south gradient in τ_a with values around 0.5 around the coast and less than about 0.1 south of the equator. As described by *Rajeev and Ramanathan* [2001], the standard error of the seasonal averages shown in this plate is about ± 0.02 or 15%, whichever is greater.

Ramanathan, 2001.

Direct and Indirect Effects of Aerosols



Lau, 2008.

Four major mechanisms interacting with monsoon

- 1) Solar Dimming Effect
- 2) Elevated Heat Pump Effect
- 3) Aerosol Microphysics Effect
- 4) Coupled Ocean-Atmosphere-Land Interactions

Solar Dimming Effect

- Both absorbing and non-absorbing aerosols cause surface cooling by blocking solar radiation from reaching the earth's surface
- In Asian monsoon regions, the solar dimming effect is especially large because of heavy pollution and frequent dust storms
- Weakening of the south Asian monsoon due to the reduction of the surface temperature gradient between the Asian land mass and the Indian Ocean

Solar Dimming Effect

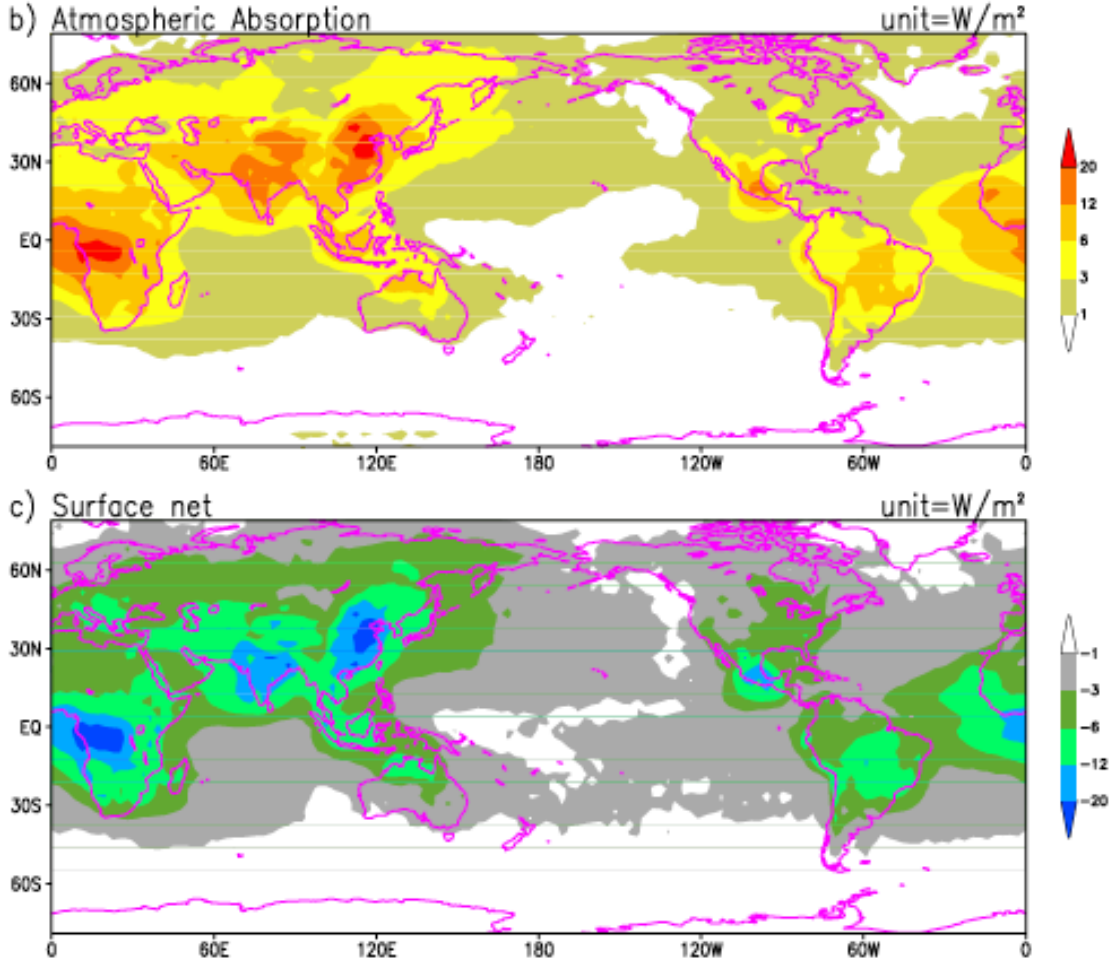


Figure 9. (a) Annual-mean anthropogenic aerosol forcing at the TOA. (b) Vertically integrated forcing in the atmosphere. (c) Forcing at the surface. The forcing calculation here includes cloud effects and uses integrated AODs, SSAs and asymmetry parameters with MODIS, GOCART and AERONET climatologies. The forcing in this figure is our standard and best estimate.

Chung, 2005.

Elevated Heat Pump Effect

- Aerosols accumulate against the southern and northern slopes of the Tibetan Plateau during April – May
- Dust and black carbon aerosols absorb solar radiation, atmosphere over northern India and southern Tibetan Plateau is heated relative to the region to the south
- Warm air rises and draws moist air from the Indian ocean into the lower levels
- Causes a northward shift of the region of region of maximum convective instability (deep convection over the foothills of the Himalayas)
- Enhanced Hadley circulation with rising motion (increased rainfall) over northern India and sinking motion (decreased rainfall) over the northern Indian Ocean/southern India

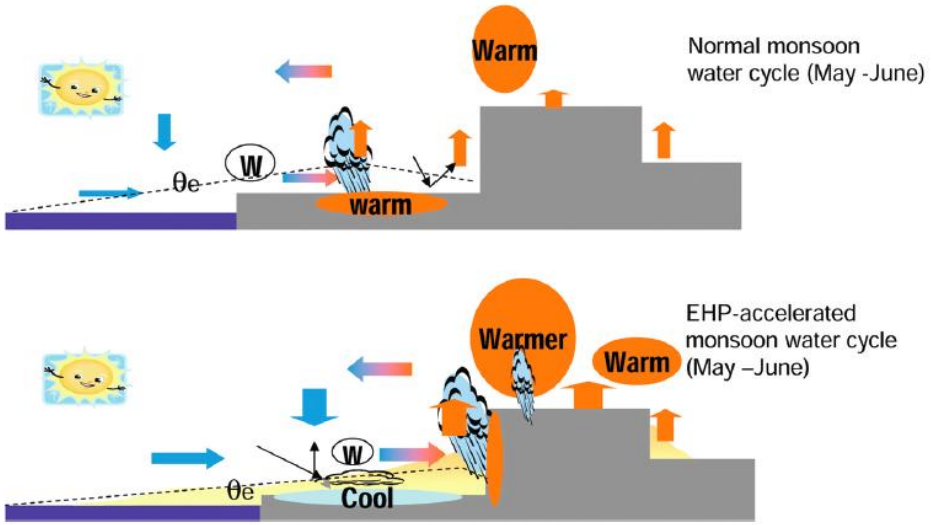


FIG. 3. Schematic showing the monsoon water cycle (top) with no aerosol forcing and (bottom) with aerosol-induced elevated heat pump effect. Low-level monsoon westerlies are denoted by W. The dashed line indicates magnitude of the low-level equivalent potential temperature θ_e. Deep convection is indicated over regions of maximum θ_e. (See text for further discussions.)

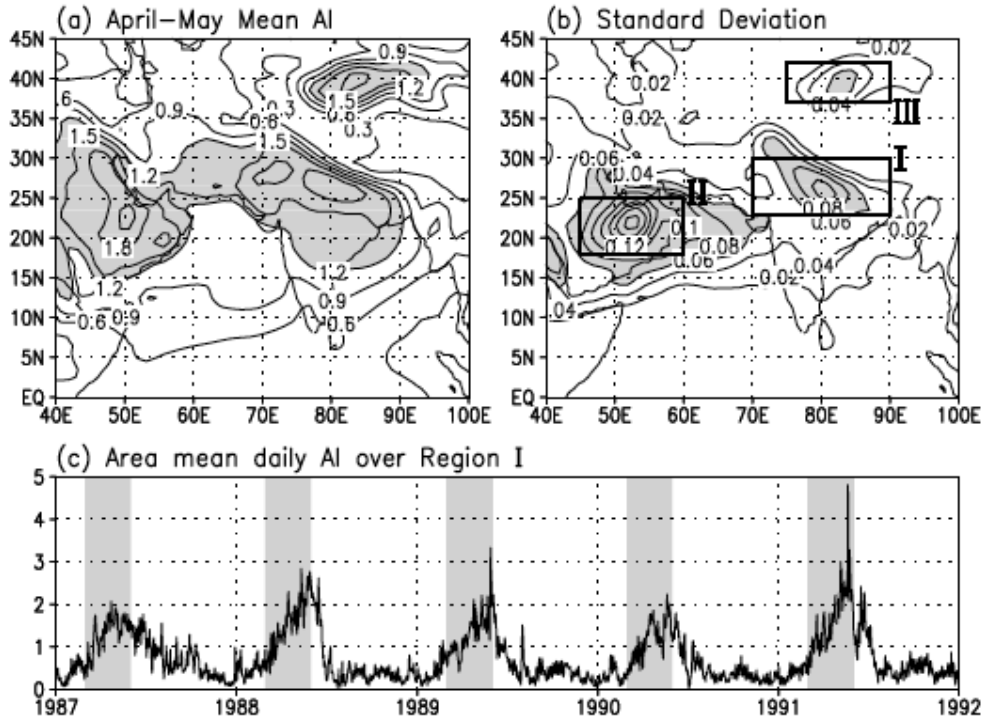


Figure 1. Climatological (1979–2001) distribution of absorbing aerosols over the Indian subcontinent and adjacent areas based on the TOMS Aerosol Index (AI) for April–May showing (a) the bi-monthly mean distribution, and (b) the monthly standard deviation, and (c) Area mean daily AI, and total rainfall (bar charts) over Region I. Key source regions are marked by numbered rectangles in Figure 1b. Shaded columns in Figure 1c mark the March–April–May season. AI is in normalized unit, and rainfall unit is in mm day^{-1}.

Lau, 2006.

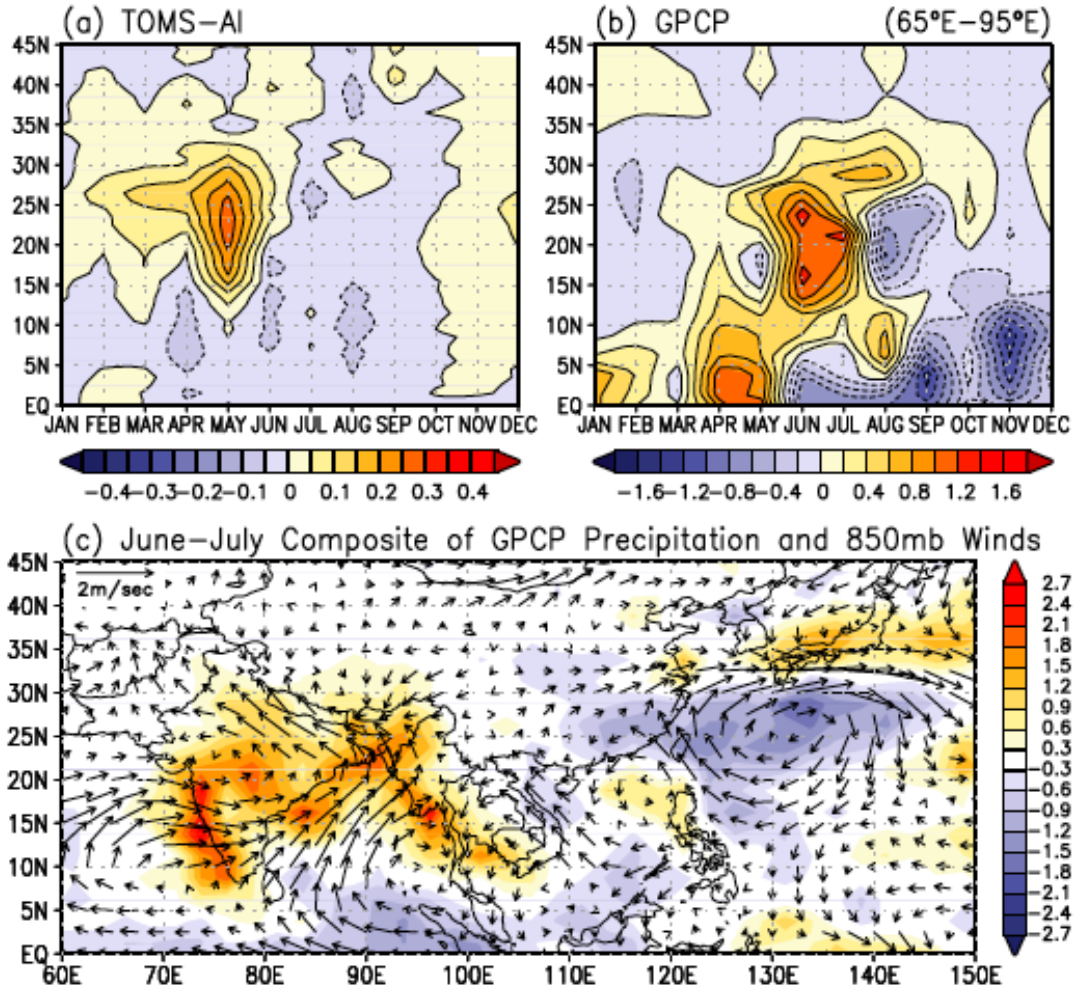
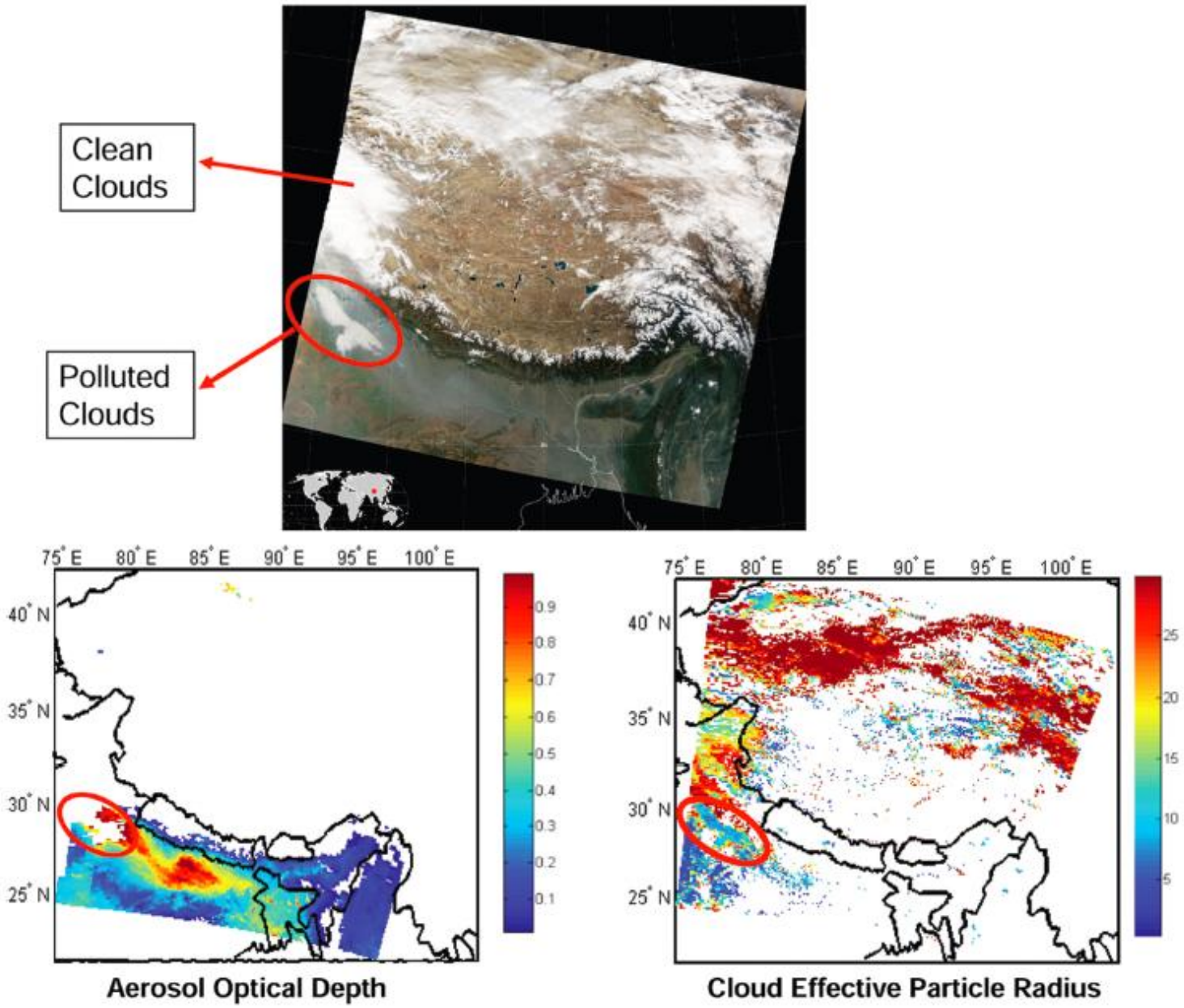


Figure 2. Time-latitude cross-sections showing composite seasonal evolution during year of high loading of absorbing aerosols of (a) the AI anomalies, and (b) the observed rainfall anomalies, and (c) composite of rainfall and 850 hPa wind pattern during years of high AI anomalies. Unit of rainfall is in mm day^{-1}, and wind is m sec^{-1}.

Lau, 2006.

Aerosol Microphysics Effect

- Aerosol increase the number of CCN in the atmosphere
- Smaller water droplets
- Increase scattering, brighten clouds
- Prolonged lifetime, reduction in precipitation


Clean Clouds
Polluted Clouds
75° E
80° E
85° E
90° E
95° E
100° E
40° N
35° N
30° N
25° N
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Aerosol Optical Depth
25
20
15
10
5
Cloud Effective Particle Radius

Lau, 2008.

Coupled Ocean-Atmosphere-Land Interactions

- The effect of aerosols ultimately depends on the interaction of the aforementioned processes
  - Effects can be strongly dependent on spatial and temporal scales (timing of monsoon)
- Also largely depends on forcing from large scale dynamics (SST and land surface processes)

Summary

Weakens Monsoon	Strengthens Monsoon
Solar Dimming Effect	Elevated Heat Pump Effect
Aerosol Microphysics Effect (?)	