Effects of aerosols on water cycle dynamics: a CEOP-II science focus

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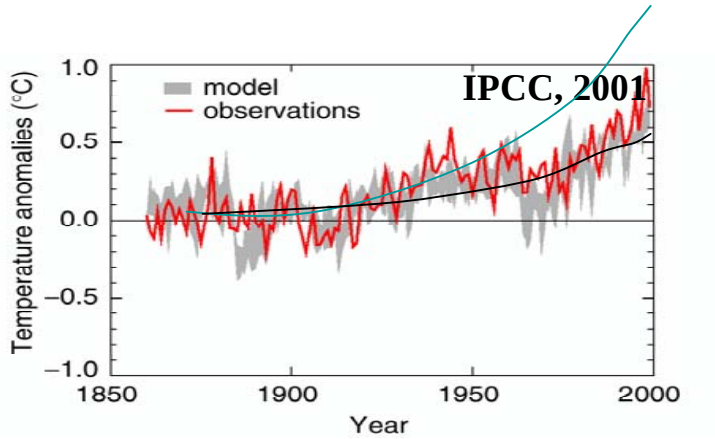
Aerosol Effects on Climate and Water Cycle

- Cools the Earth surface → reduces greenhouse warming
- Changes cloud structure → suppresses or enhances rain
- Redistributes heat sources and sinks → changes atmospheric circulation → moisture and aerosol transport



Biomass burning

Urban/Industrial pollution

Desert Dust

Aerosol Impacts on Climate

- Direct effect

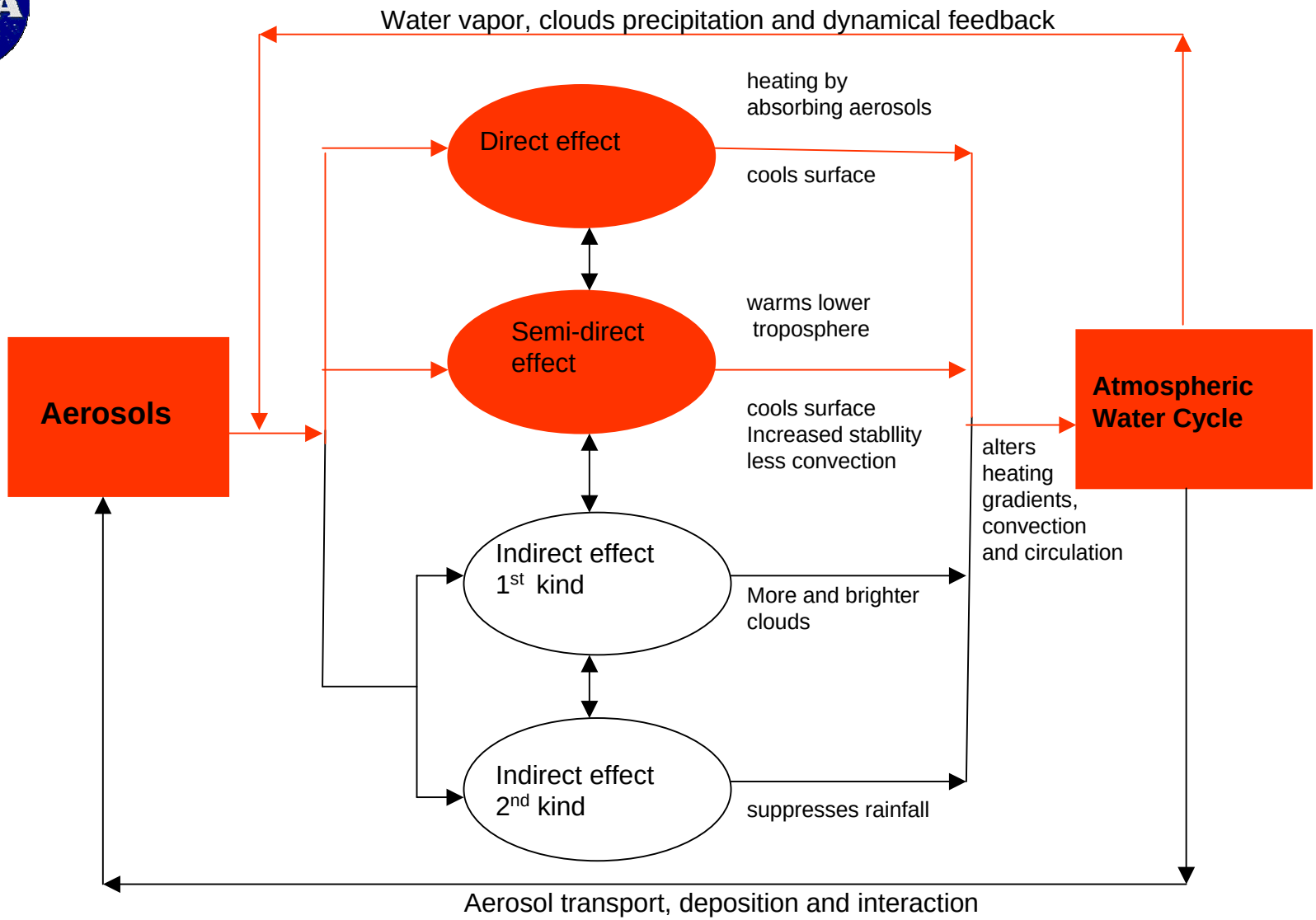
  Cooling effects due to reflection of sunlight
- Semi-direct effects (absorbing aerosols)

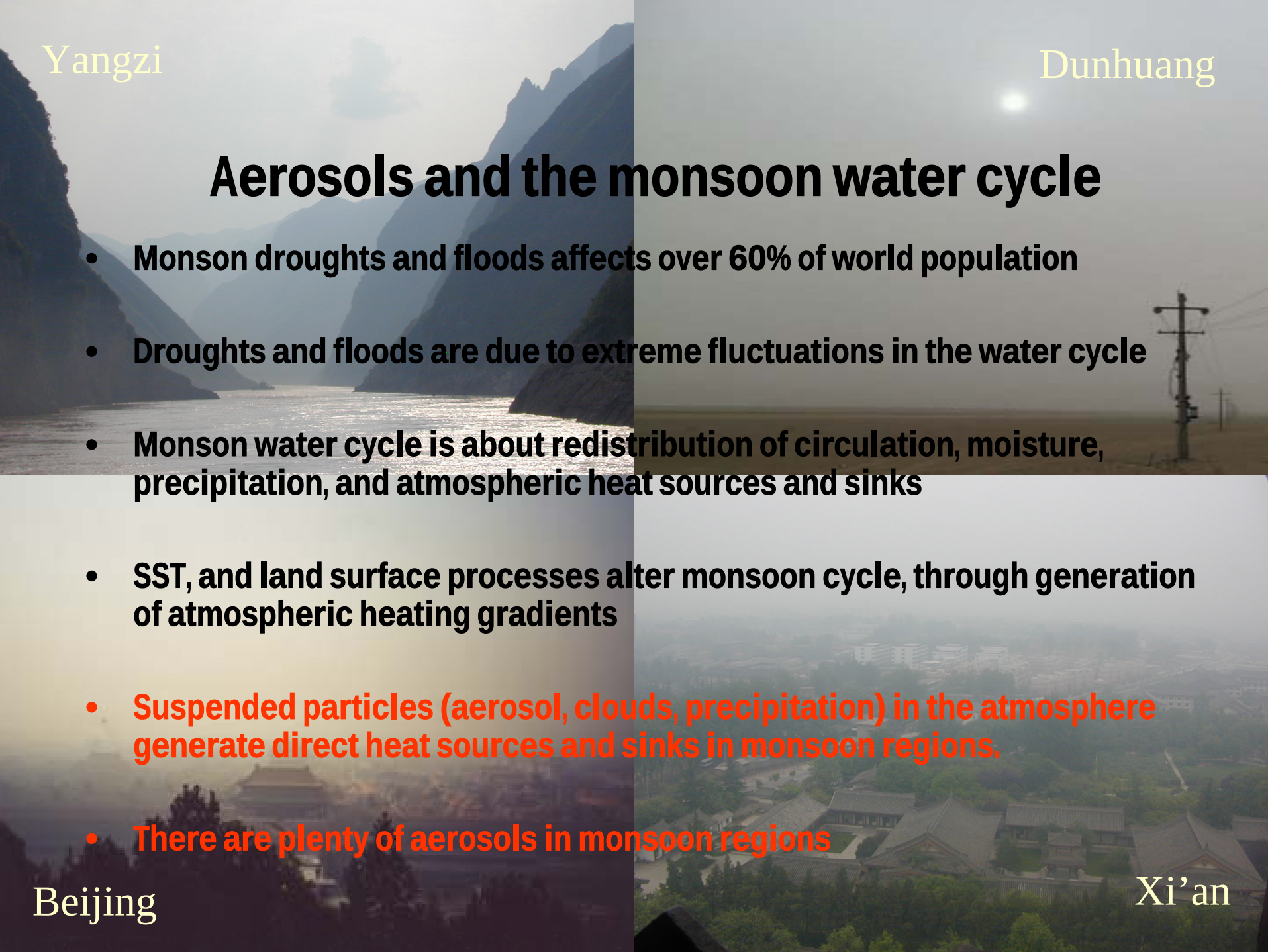
  Increase stablity (reduce convective potential) by surface cooling and heating in lower troposphere

  Enhance mid-low level heating and moisture convergence increased convection, and rainfall
- Indirect effects

  1st type (Twomey effect): more CCN, more clouds with smaller cloud droplets, and enhanced cloud albedo

  2nd type (Albrecht effect): reduced coalesence, drizzle suppression, longer cloud life time
- Aerosol transport and interaction with large scale dynamics
- Aerosol-aerosol chemistry interaction


Water vapor, clouds precipitation and dynamical feedback
heating by
absorbing aerosols
Direct effect
cools surface
warms lower
troposphere
Semi-direct
effect
cools surface
Increased stabllity
less convection
Aerosols
Atmospheric
Water Cycle
alters
heating
gradients,
convection
and circulation
Indirect effect
1st kind
More and brighter
clouds
Indirect effect
2nd kind
suppresses rainfall
Aerosol transport, deposition and interaction

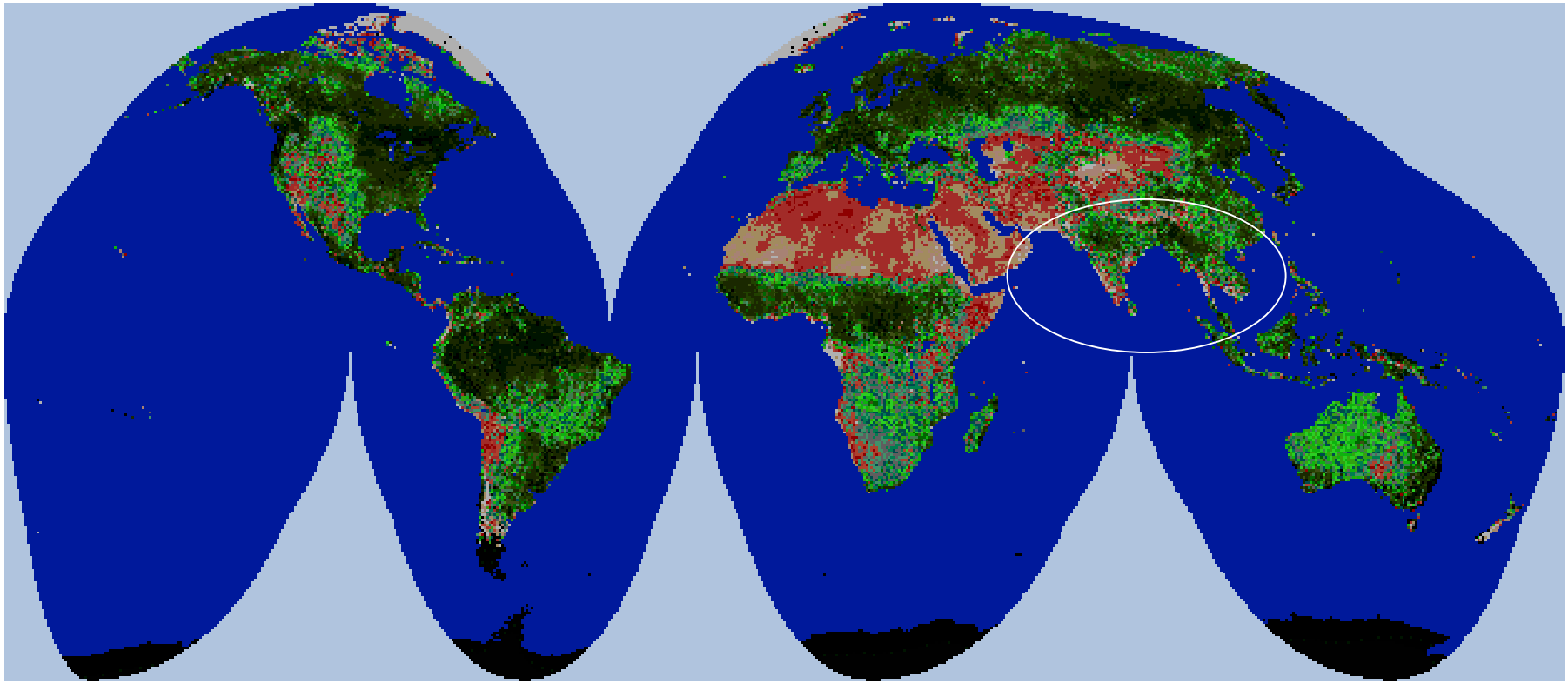


Aerosols and the monsoon water cycle

- Monson droughts and floods affects over 60% of world population
- Droughts and floods are due to extreme fluctuations in the water cycle
- Monson water cycle is about redistribution of circulation, moisture, precipitation, and atmospheric heat sources and sinks
- SST, and land surface processes alter monsoon cycle, through generation of atmospheric heating gradients
- Suspended particles (aerosol, clouds, precipitation) in the atmosphere generate direct heat sources and sinks in monsoon regions.
- There are plenty of aerosols in monsoon regions

Surface vegetation showing bare soil regions (red) :

sources of dust aerosols during boreal summer



NDVI image for 21-31 August 2000, from Pathfinder AVHRR

Saharan Dust Outbreaks

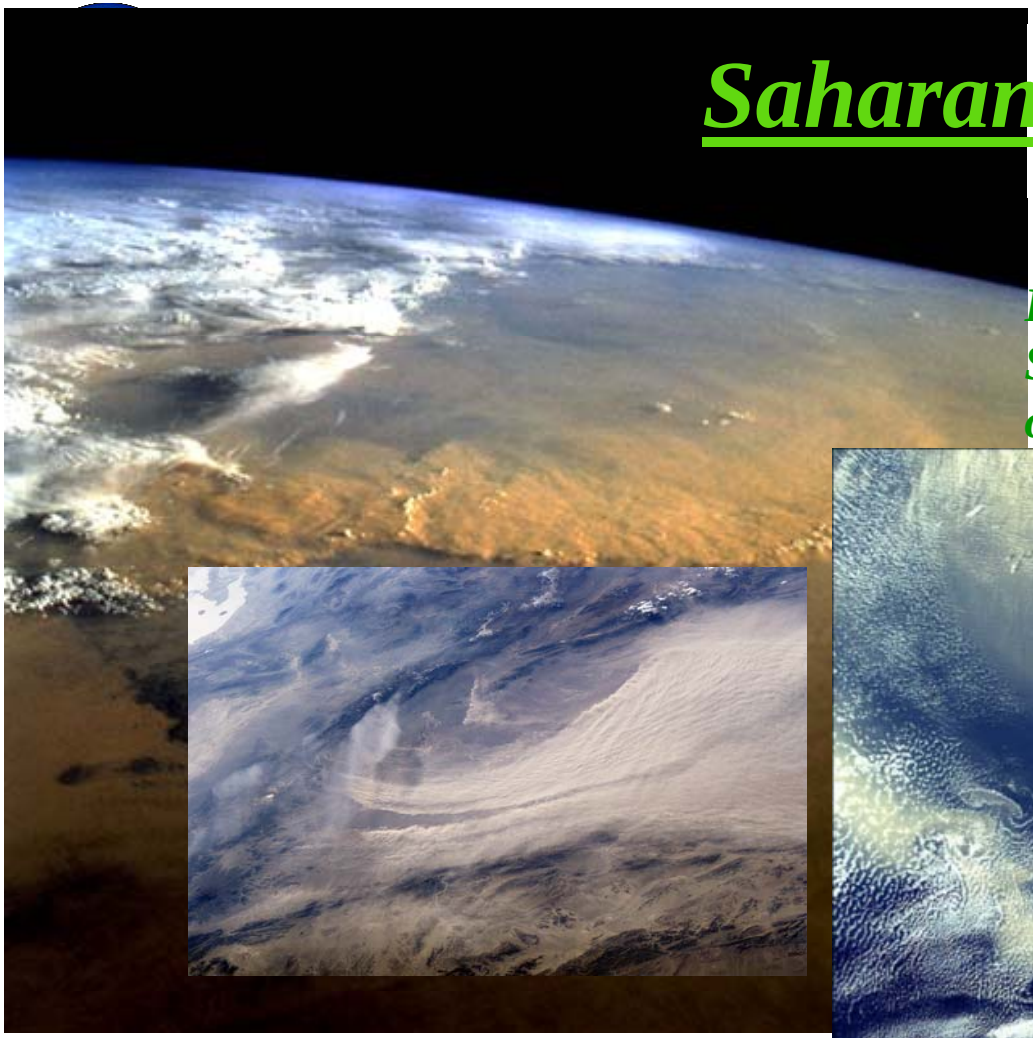
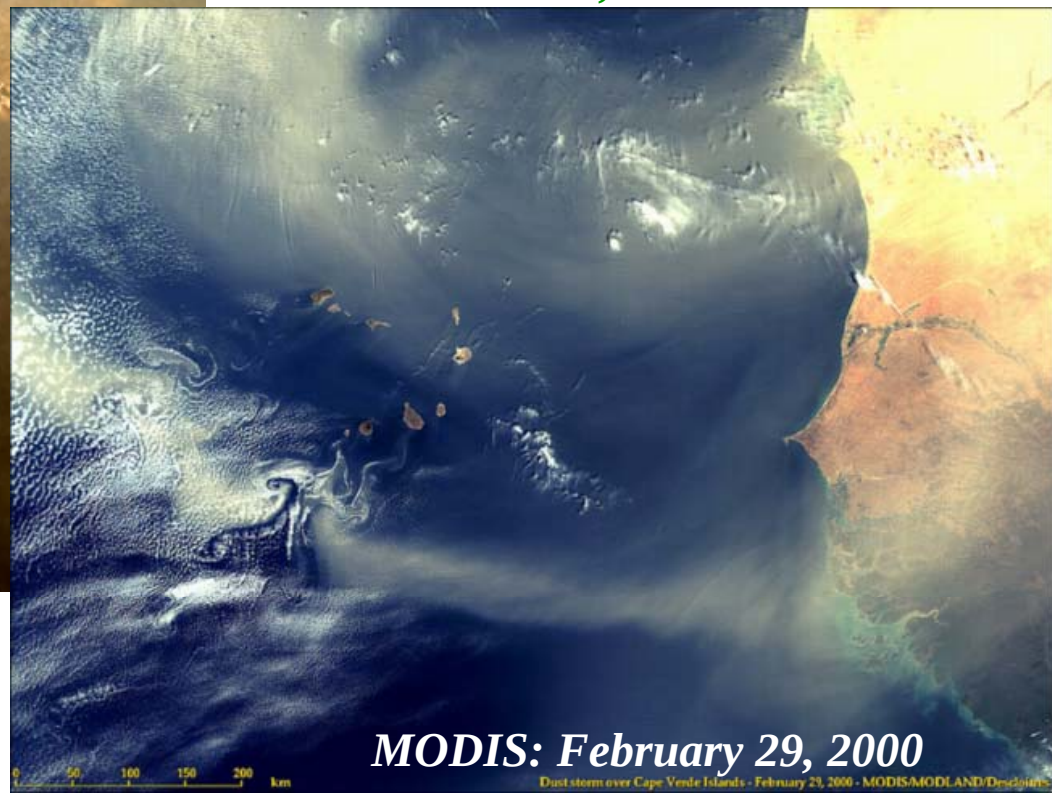
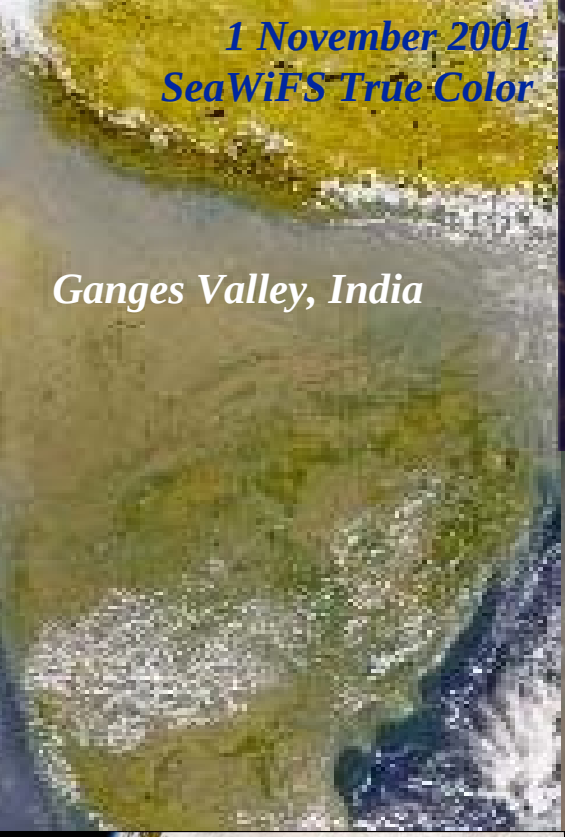
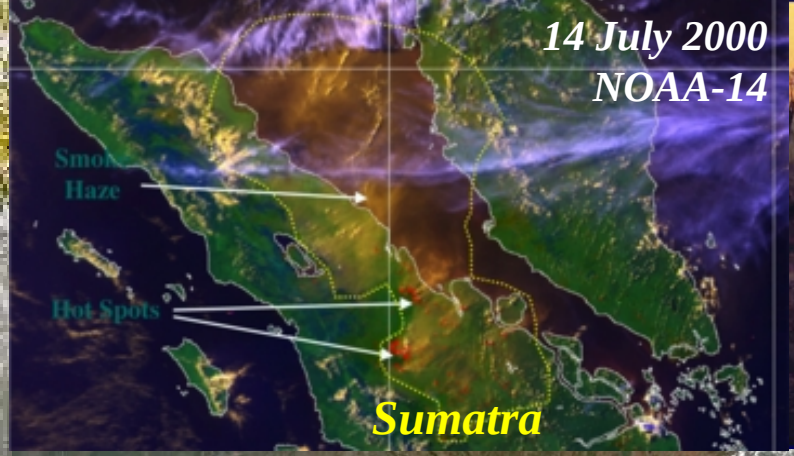


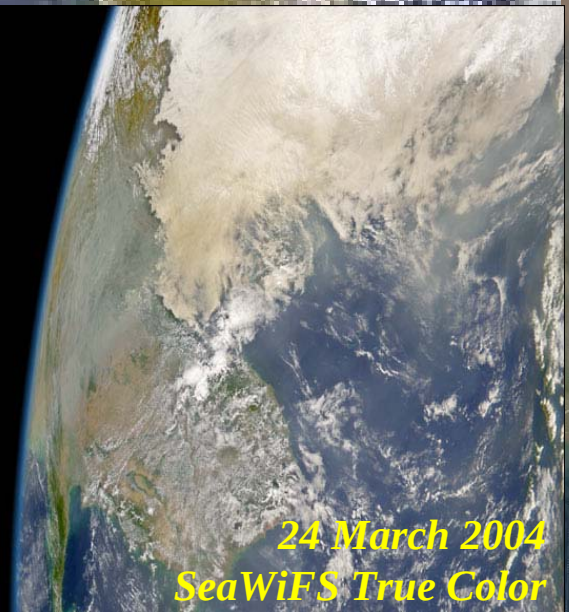
Photo taken from Space Shuttle
Fierce dust front over Libya
Photo taken from International Space Station of dust plumes over Kerman Desert, Iran

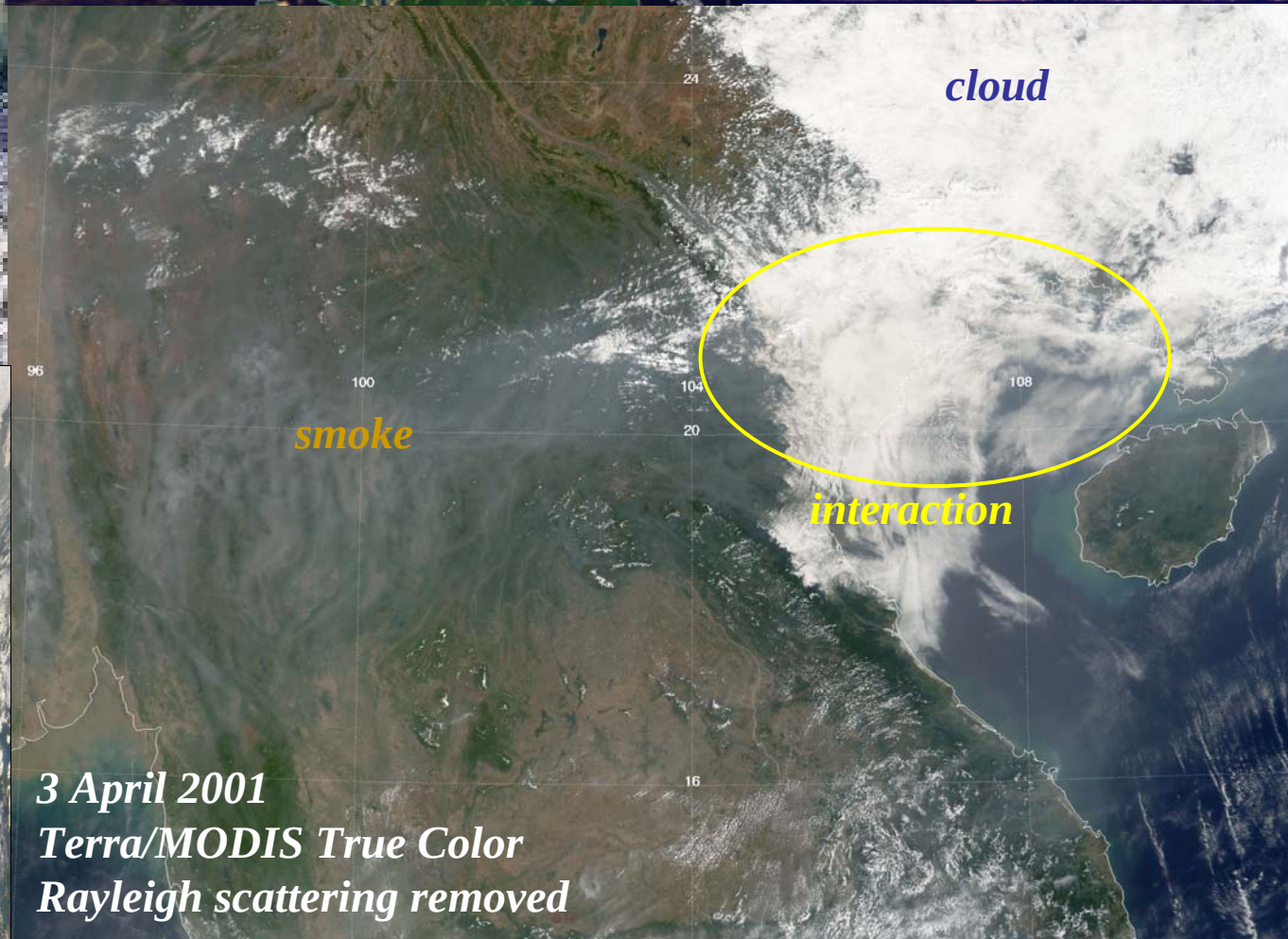


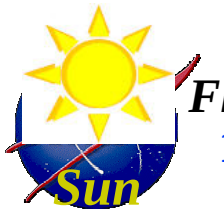
RGB image acquired by Terra/MODIS
Dust swept through west coast of Africa to Cape Verde


1 November 2001
SeaWiFS True Color
Ganges Valley, India


14 July 2000
NOAA-14
Smoke
Haze
Hot Spots
Sumatra


24 March 2004
SeaWiFS True Color


cloud
smoke
interaction
3 April 2001
Terra/MODIS True Color
Rayleigh scattering removed
24
96
100
104
108
20
16



Sun overhead

Flux (Watt/m²)

1360 ↓ 81 ↑

Clear Sky

1098 ↓ 32 ↑

ARF TOA = 53 Watt/m²

1360 ↓ 134 ↑

Haze / Sulfate

1039 ↓ 30 ↑

Both Cool Earth-Atmosphere

ARF TOA = 78 Watt/m²

1360 ↓ 159 ↑

Both Warm Atmosphere

Mineral Dust

918 ↓ 27 ↑

Ocean

ARF surf = 57 Watt/m²

ARF surf = 175 Watt/m²

Both Cool Surface

Sun overhead

Flux (Watt/m²)

1360 ↓ 339 ↑

Clear Sky

1118 ↓ 331 ↑

Warm Earth-Atmosphere

ARF TOA = – 8 Watt/m²

1360 ↓ 331 ↑

Warm Atmosphere

Mineral Dust

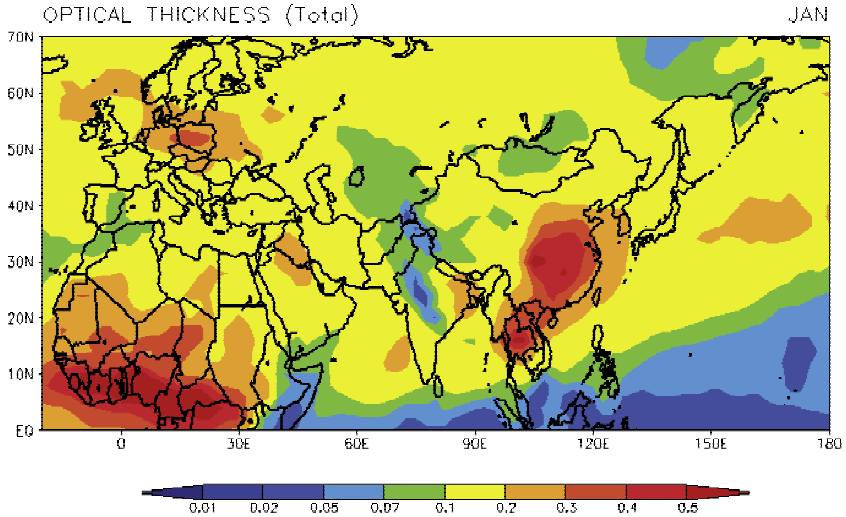
974 ↓ 194 ↑

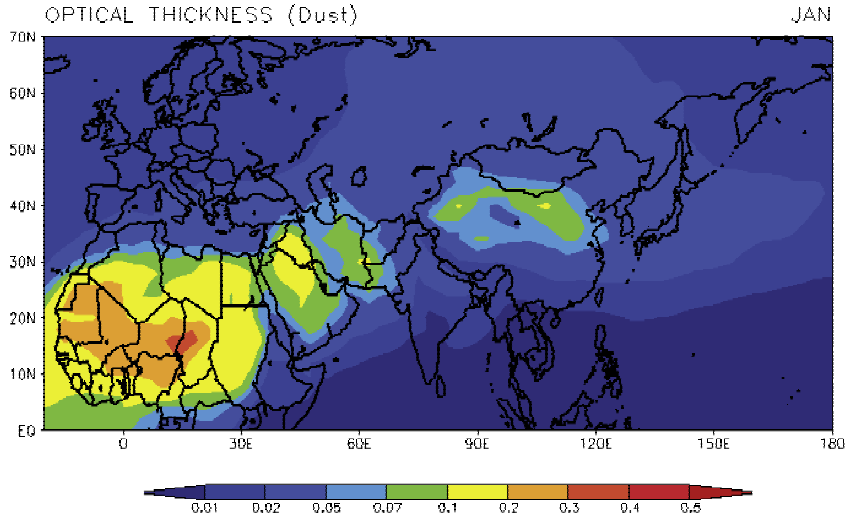
Desert

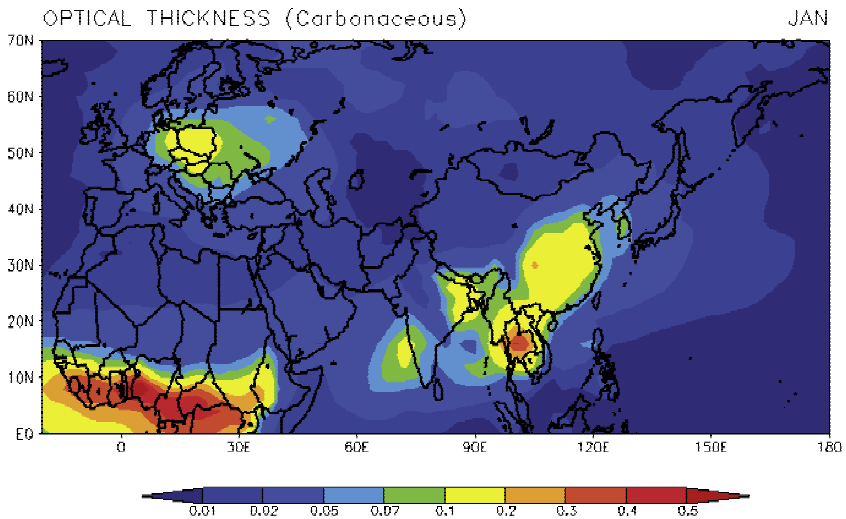
ARF surf = 7 Watt/m²

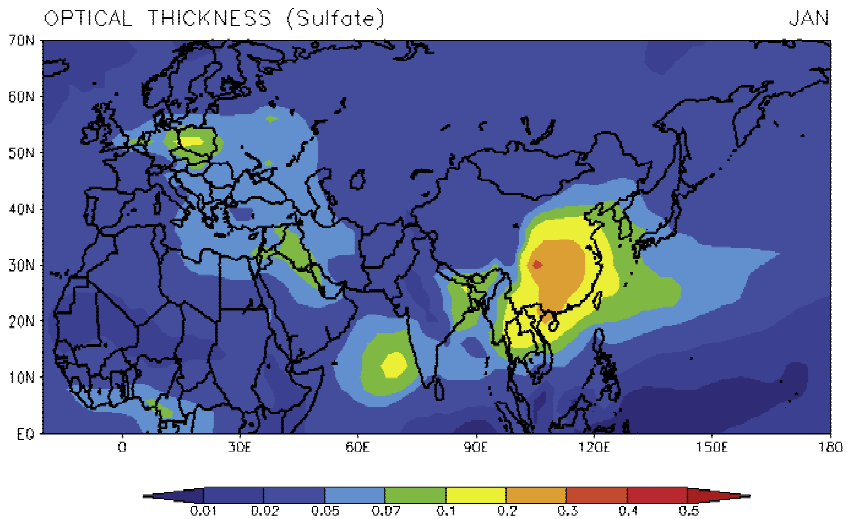
Cool Surface

GOCART Monthly Aerosol Optical Thickness

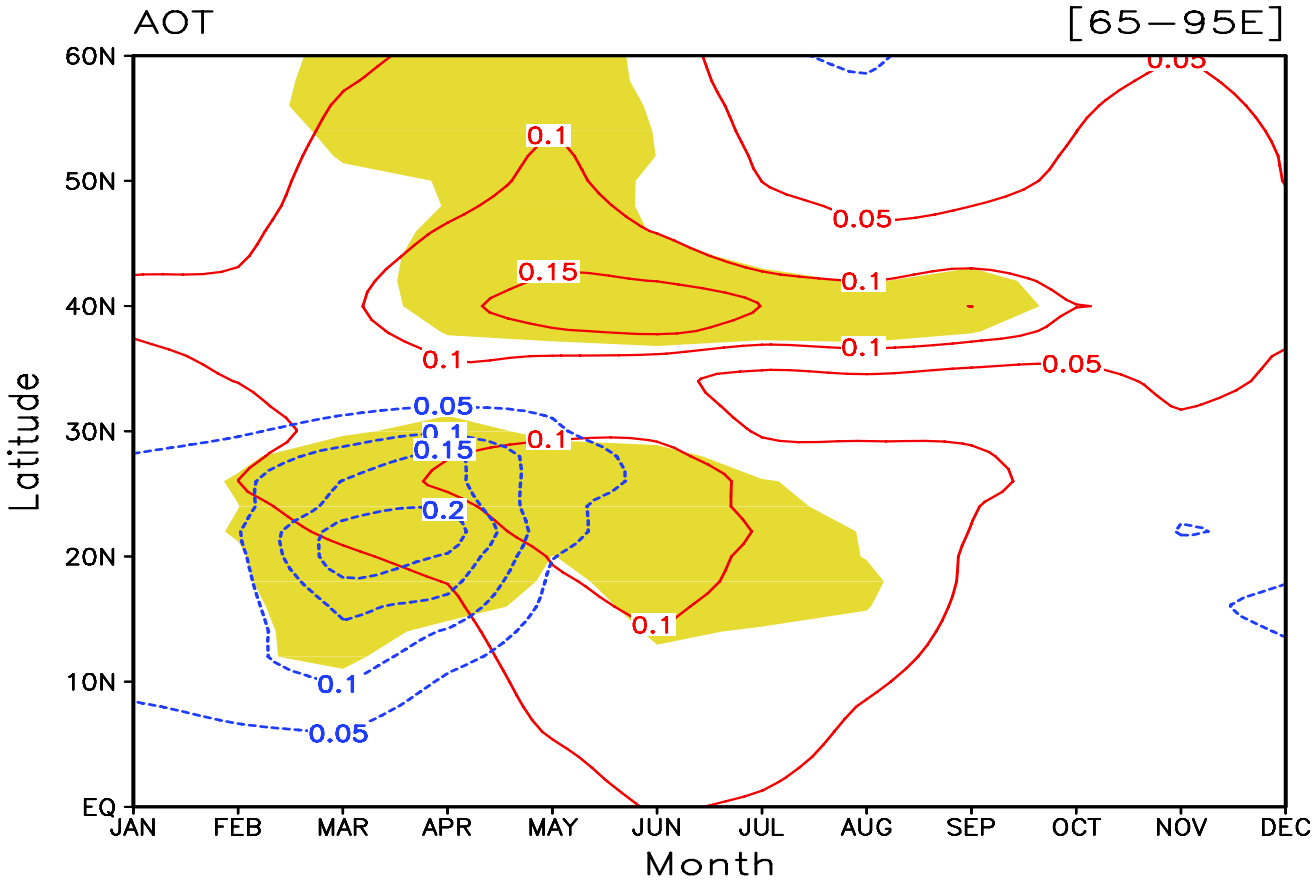








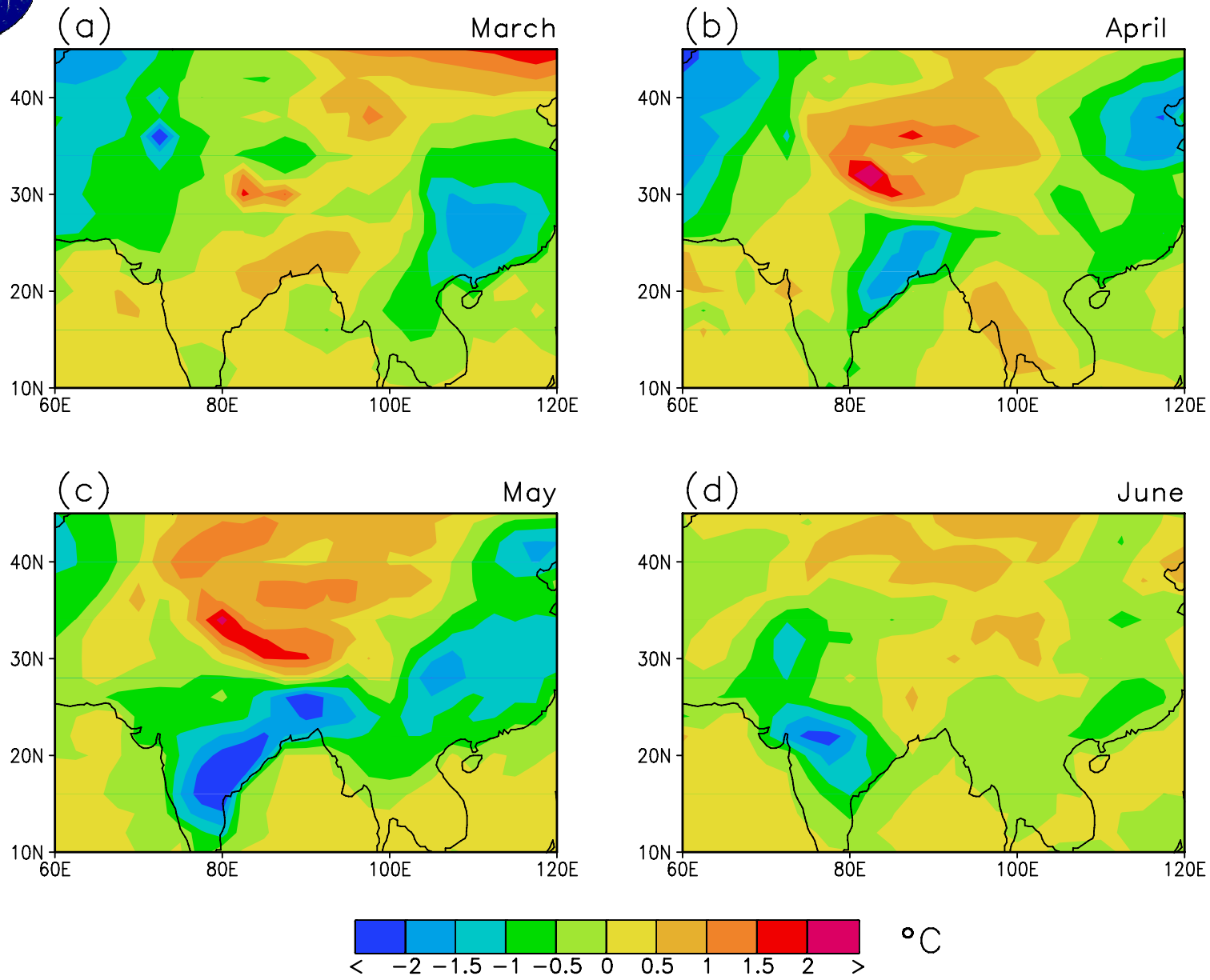
Aerosol optical thickness around the Tibetan Plateau



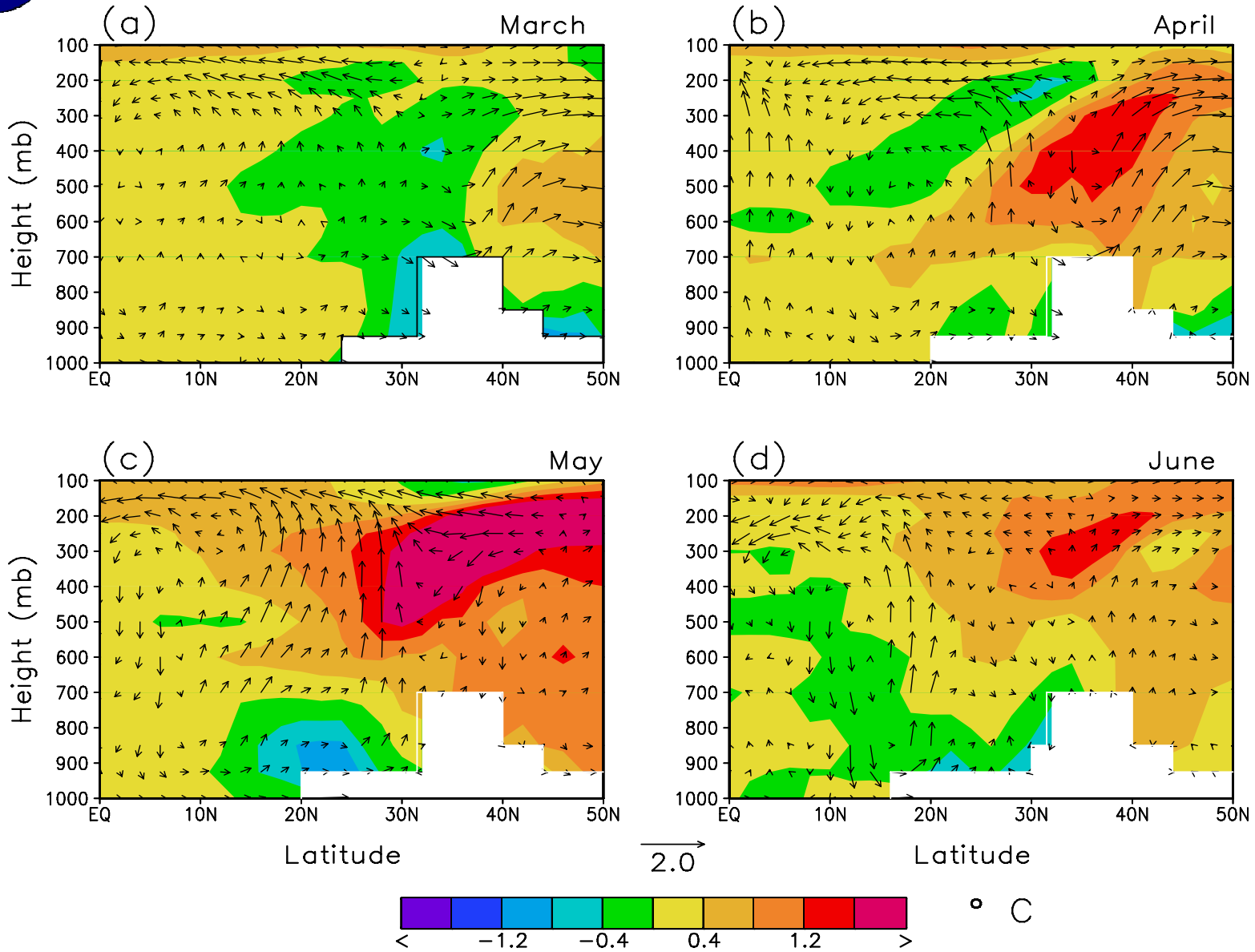
Red line: dust aerosol Blue line: Carbonaceous aerosol

Yellow shading: AOT of all aerosols > 0.15

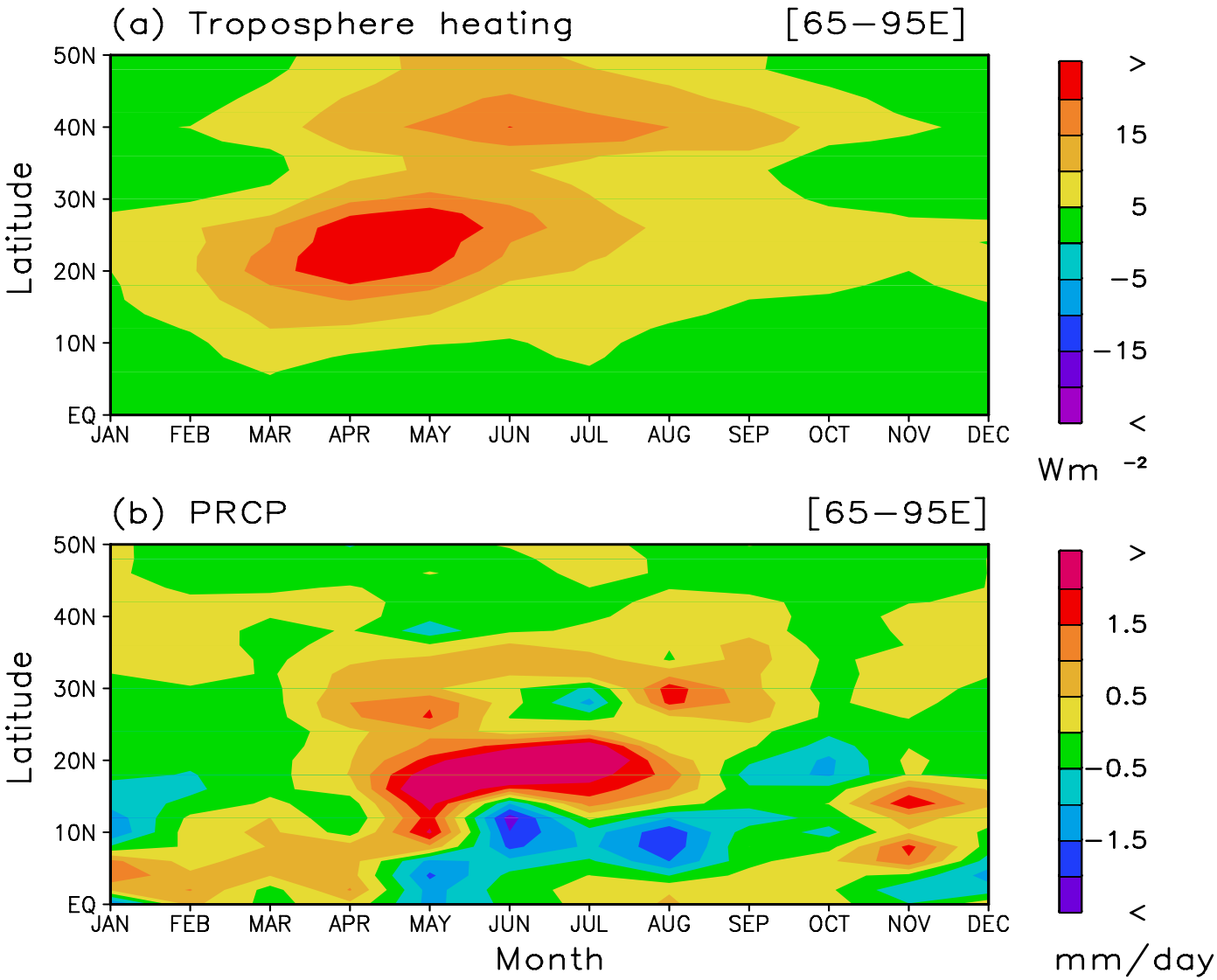
Anomalies of surface air temperature



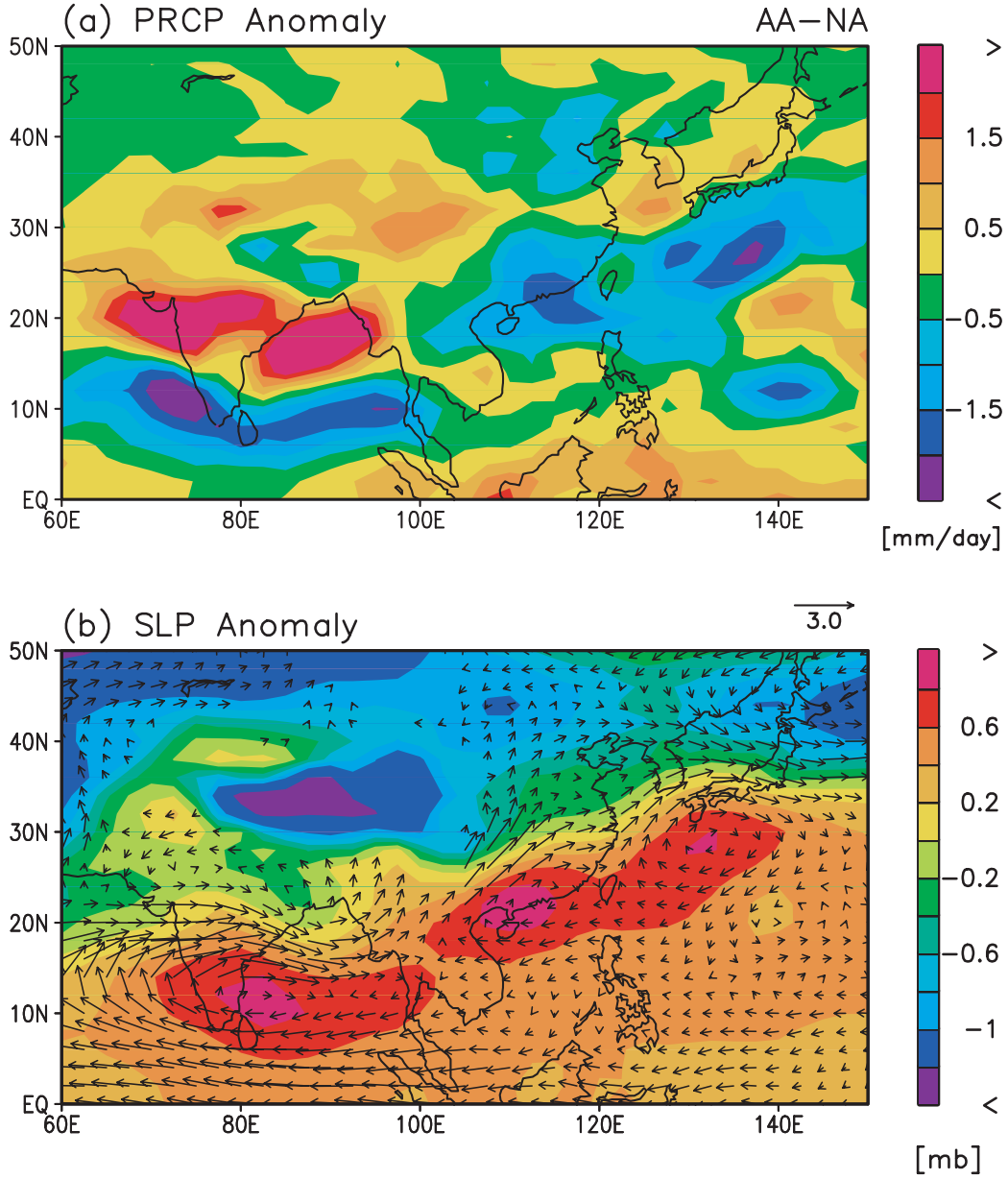
Anomalies of vertical temperature (80-100E)

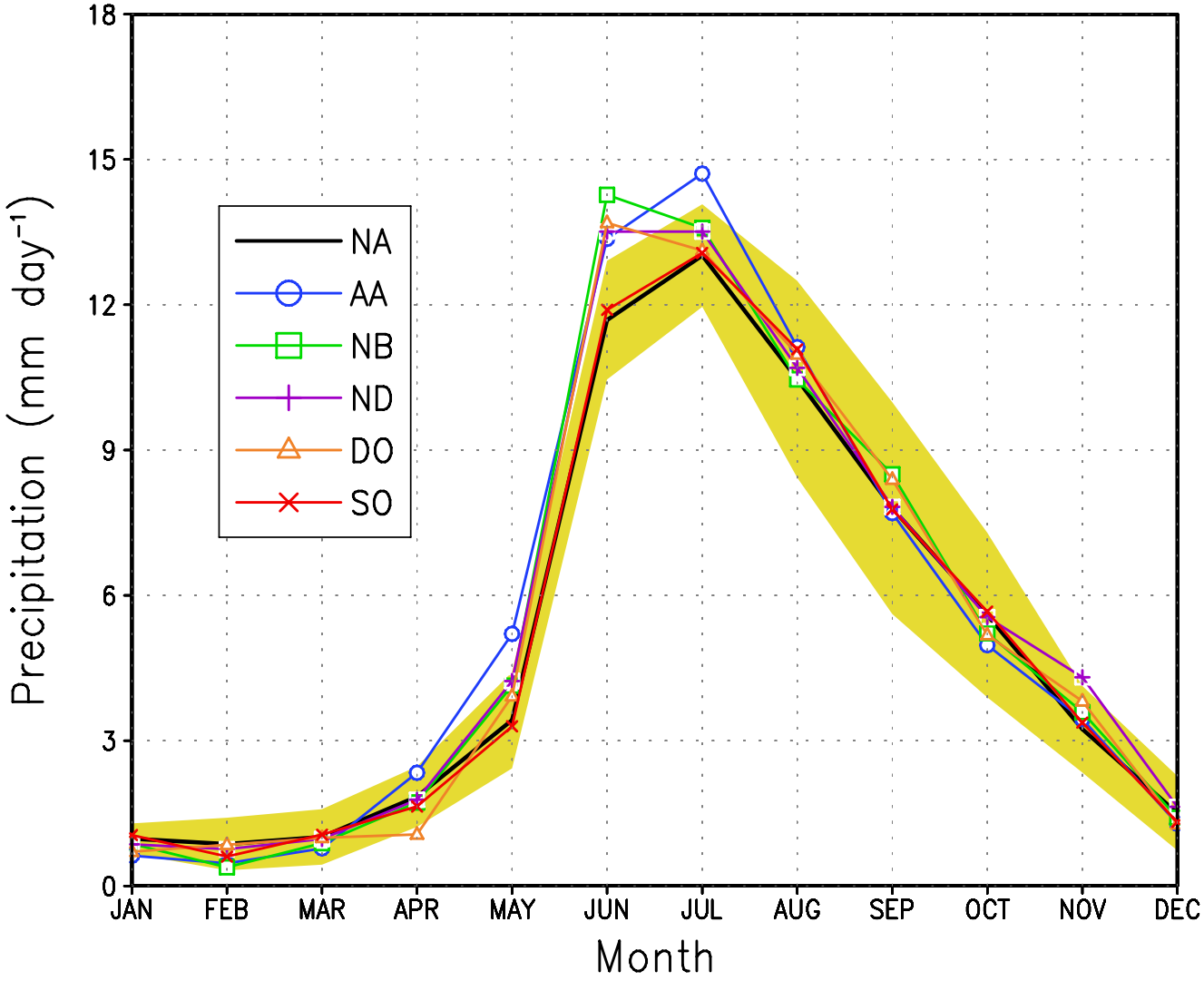


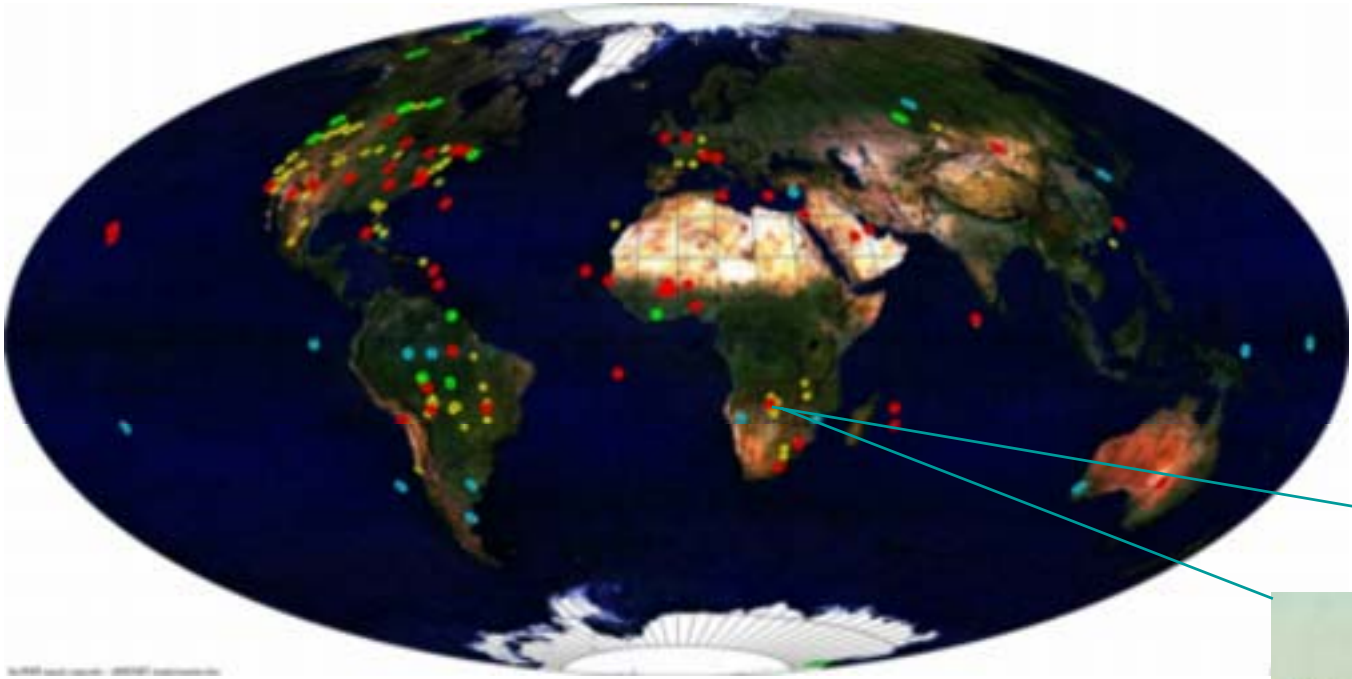
Anomalies of shortwave heating



Anomalies of summer SLP and 850hPa wind




Precipitation (mm day⁻¹)
18
15
12
9
6
3
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
NA
AA
NB
ND
DO
SO

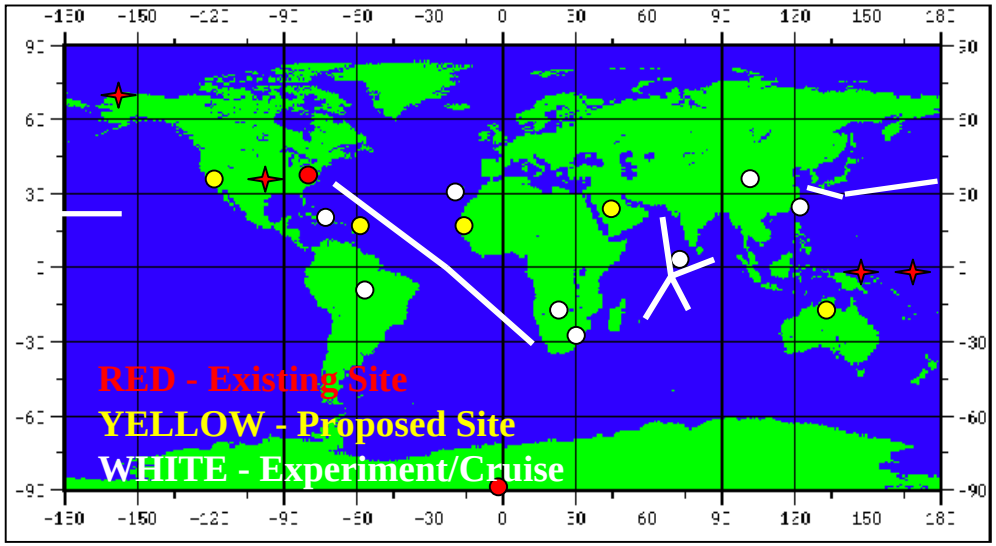


***By April 2002, there are about 180 sun-sky scanning spectral radiometers on-line and some are operated since 1993.**

- **Automatic recording and transmitting Sun/Sky Photometers**
- **Data Base: Aerosol optical thickness, size distribution, phase function & precipitable water**
- **Collaborative: NASA – instruments/sites and centralized calibration & database including non-NASA – instruments/sites**

http://aeronet.gsfc.nasa.gov

Global MPL-NET *



*http://virl.gsfc.nasa.gov/mpl-net/ ***(E. Welton)***

- **Altitude: 60 km (maximal)**
- **Sensor Characteristics:**
  - ***Eye Safe***
  - **Nd:YLF diode pumped laser with pulse energy of 10 µJ**
  - **visible wavelength at 0.532 µm**
  - **beam divergence 1.2 mrad.**
  - **FOV 50 (100) µrad. for transmitter (receiver)**
  - **pulse repetition rate 2500 Hz**
  - **30-300 m vertical resolution**
  - **1 month recording capacity**
  - **self-calibration against molecular scattering**

Atmospheric Brown Cloud

ACE-Asia: Aerosol Characterization Experiment - Asia, 2001; and regional follow-ups 2002-2003
TRACE-P: TRAnsport & Chemical Evolution over the Pacific, 2001

APEX: Asian Atmospheric Particle Environment Change Studies, 1999-2003, **Nakajima et al.**

EAST-AIRE: East Asian Study of Tropospheric Aerosols - International Regional Experiment, **Li et al.**

BASE-ASIA: Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment, **Tsay et al.**

INDOEX: INDian Ocean EXperiment, 1999, **Ramanathan et al.**

ABC: Atmospheric Brown Clouds, **Ramanathan et al.**

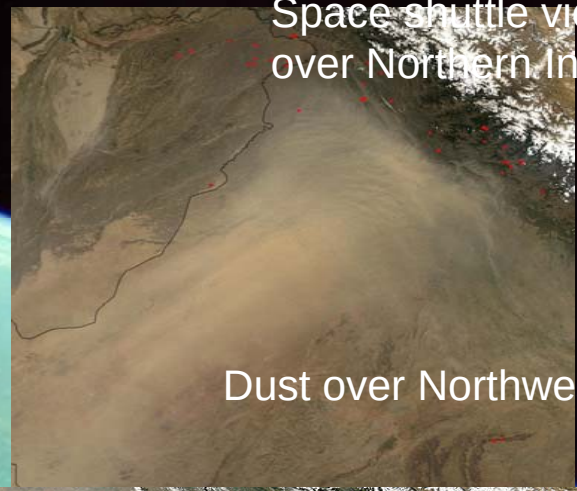
CEOP-II Implementation for Aerosol-water cycle interactions

- Add to the existing select CEOP reference sites measurement platforms of aerosols characteristics e.g. Himalayas, Tibet, West Africa, Indonesia, LBA…
- Include current aerosol measurement platforms:
  - AERONET
  - MPL-NET
  - ABC
  - New initiative on Indo-Gangetic Aerosol-Monsoon water cycle interactions (IGAM)

Imperatives for an Indo-Gangetic Basin field campaign on aerosol-water cycle dynamic interaction

- The livelihood of >600 million people from Lahore to Calcutta depend on a 2 to 3 month monsoon rainfall
- Meltwater from the Himalayas sustain agriculture thru the dry season
- Glaciers are rapidly shrinking jeopardizing the long-term water supply
- Aerosol loading is extremely high throughout the year and is increasing with the growth of the Indian economy (8%/yr)
- The impact of aerosols on health, agricultural productivity and the monsoon water cycle dynamics is uncertain

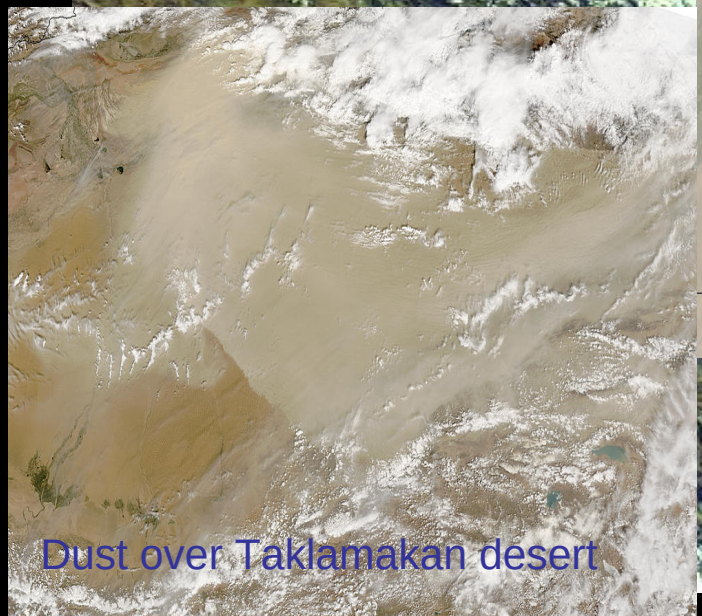
Smok, haze, clouds over Indo-Gangetic Plain



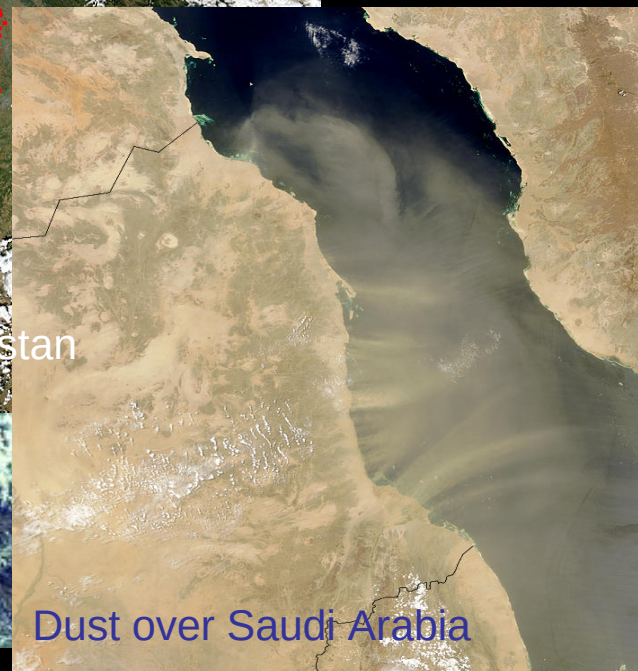
Space shuttle view of haze, pollution over Northern India, from Tibet

Dust over Northwest India and Pakistan

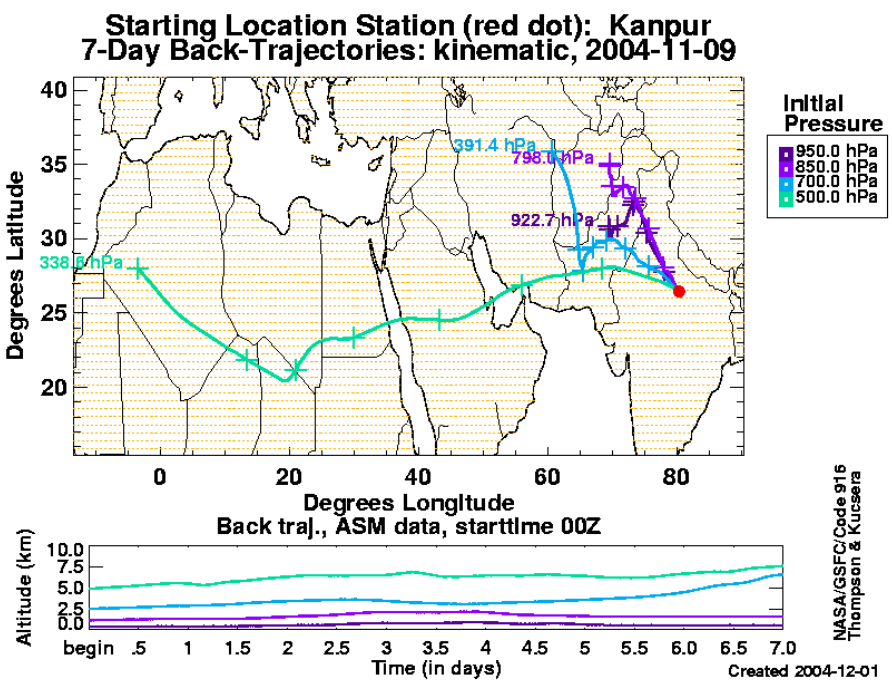
Dust, smoke, fire over Northwestern India/Pakinstan

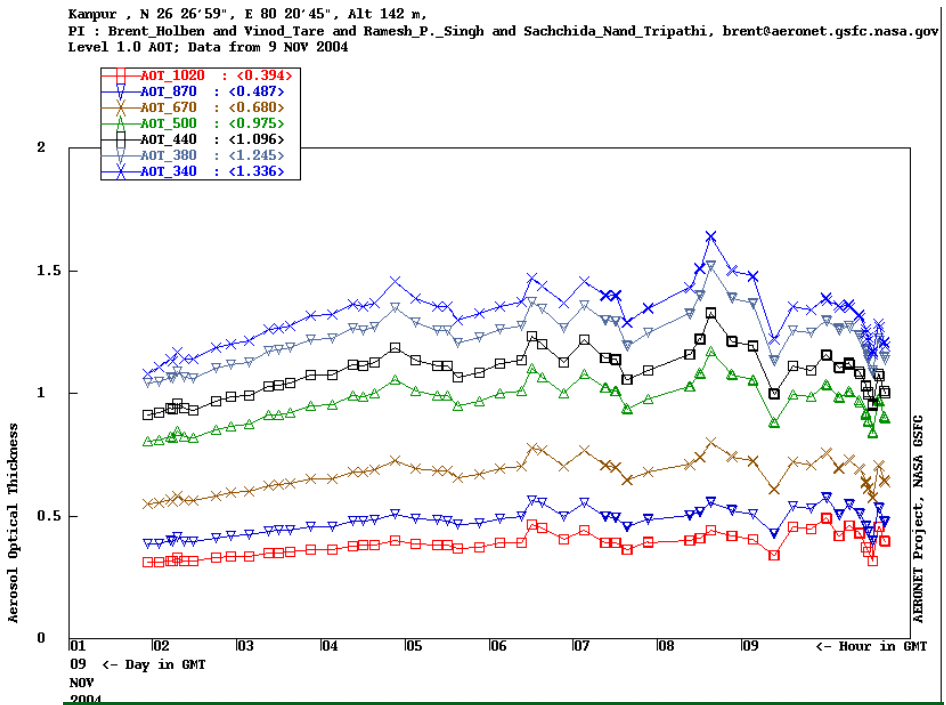


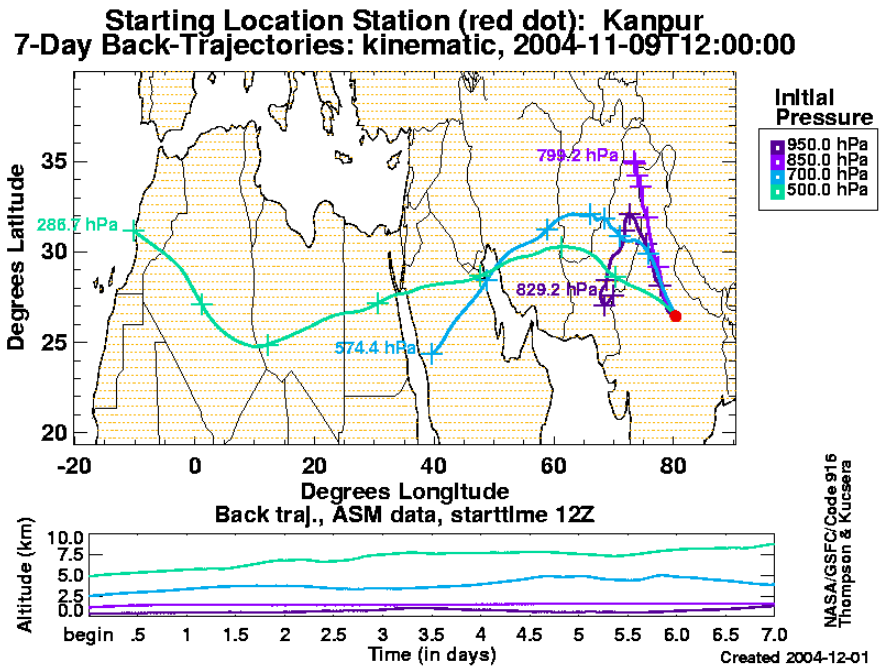
Dust over Taklamakan desert

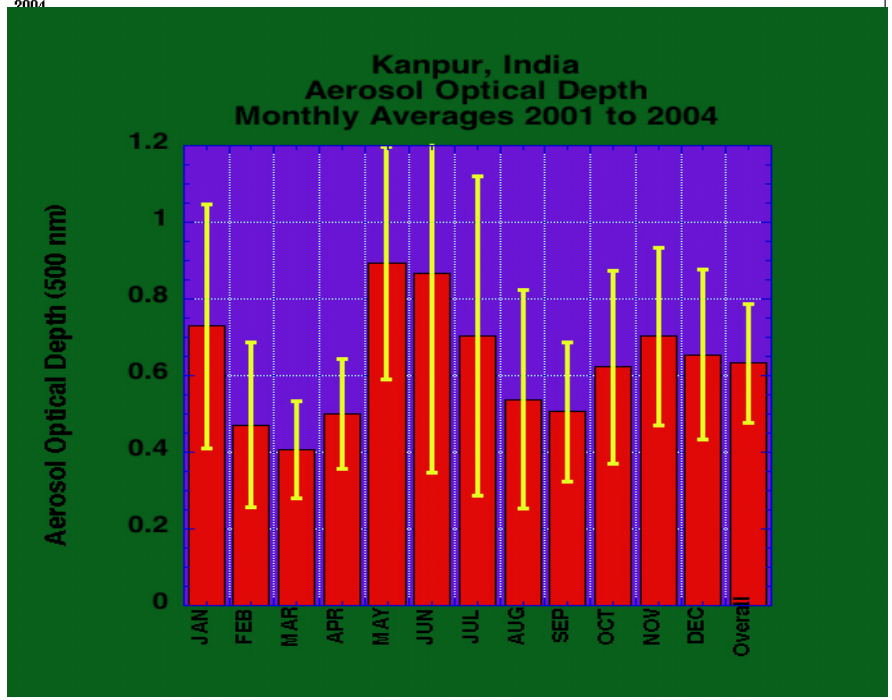


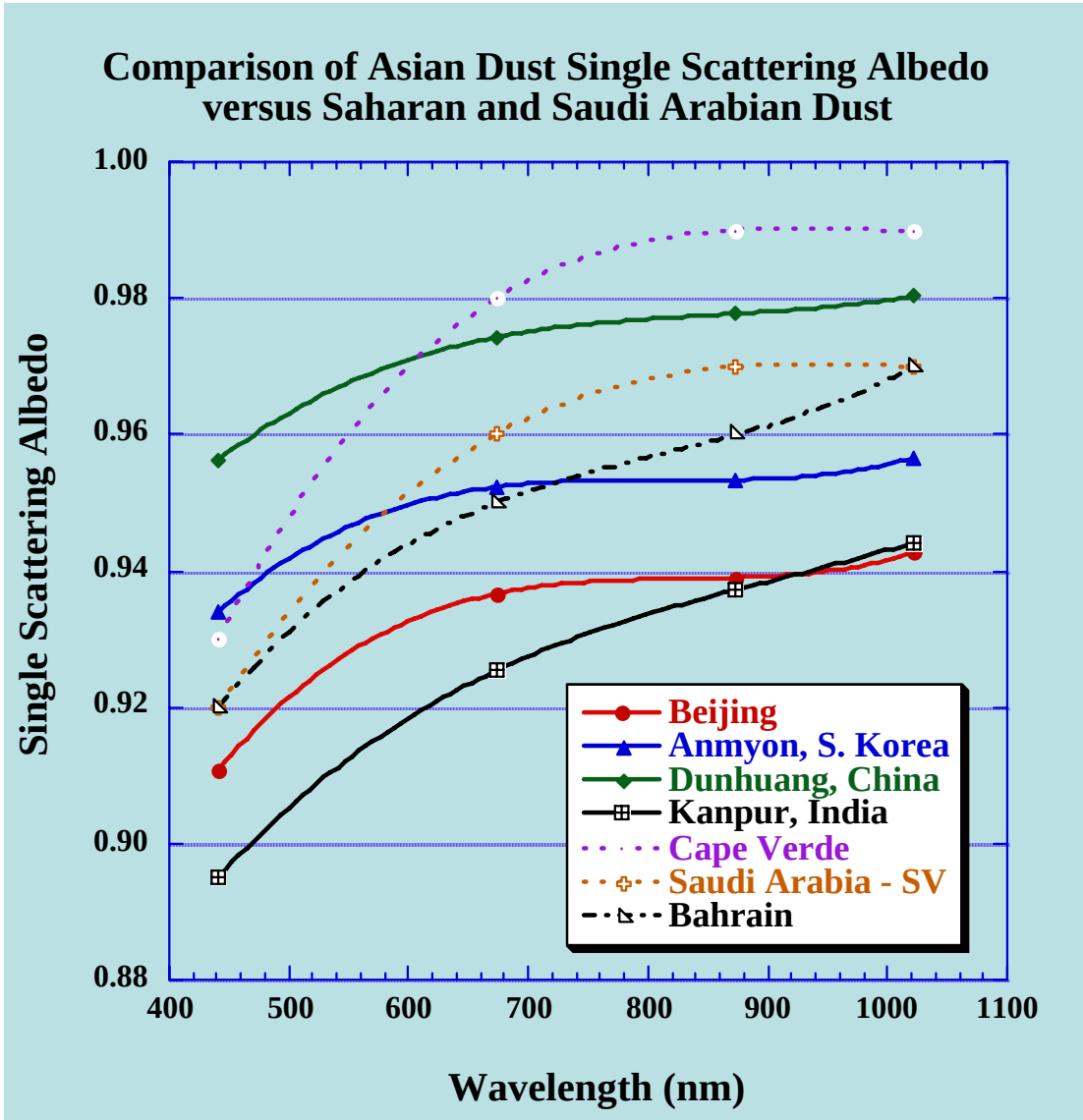
Dust over Saudi Arabia


Starting Location Station (red dot): Kanpur
7-Day Back-Trajectories: kinematic, 2004-11-09
Initial Pressure
950.0 hPa
850.0 hPa
700.0 hPa
500.0 hPa
391.4 hPa
798.0 hPa
922.7 hPa
338.6 hPa
Degrees Latitude
Degrees Longitude
Back traj., ASM data, starttime 00Z
Altitude (km)
Time (in days)
begin
NASA/GSFC/Code 916
Thompson & Kucsera
Created 2004-12-01


Kanpur , N 26 26'59", E 80 20'45", Alt 142 m,
PI : Brent_Holben and Vinod_Tare and Ramesh_P._Singh and Sachchida_Nand_Tripathi, brent@aeronet.gsfc.nasa.gov
Level 1.0 AOT; Data from 9 NOV 2004
AOT_1020 : <0.394>
AOT_870 : <0.487>
AOT_670 : <0.680>
AOT_500 : <0.975>
AOT_440 : <1.096>
AOT_380 : <1.245>
AOT_340 : <1.336>
Aerosol Optical Thickness
<- Hour in GMT
09 <- Day in GMT
NOV
2004
AERONET Project, NASA GSFC


Starting Location Station (red dot): Kanpur
7-Day Back-Trajectories: kinematic, 2004-11-09T12:00:00
Initial Pressure
950.0 hPa
850.0 hPa
700.0 hPa
500.0 hPa
799.2 hPa
286.7 hPa
829.2 hPa
574.4 hPa
Degrees Latitude
Degrees Longitude
Back traj., ASM data, starttime 12Z
Altitude (km)
Time (in days)
begin
NASA/GSFC/Code 916
Thompson & Kucsera
Created 2004-12-01


Kanpur, India
Aerosol Optical Depth
Monthly Averages 2001 to 2004
Aerosol Optical Depth (500 nm)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Overall


Comparison of Asian Dust Single Scattering Albedo versus Saharan and Saudi Arabian Dust
Single Scattering Albedo
1.00
0.98
0.96
0.94
0.92
0.90
0.88
400
500
600
700
800
900
1000
1100
Wavelength (nm)
Beijing
Anmyon, S. Korea
Dunhuang, China
Kanpur, India
Cape Verde
Saudi Arabia - SV
Bahrain

Working Hypotheses for a "Indo-Gangetic Aerosol – Monsoon Water Cycle Initiative" (IGAM)

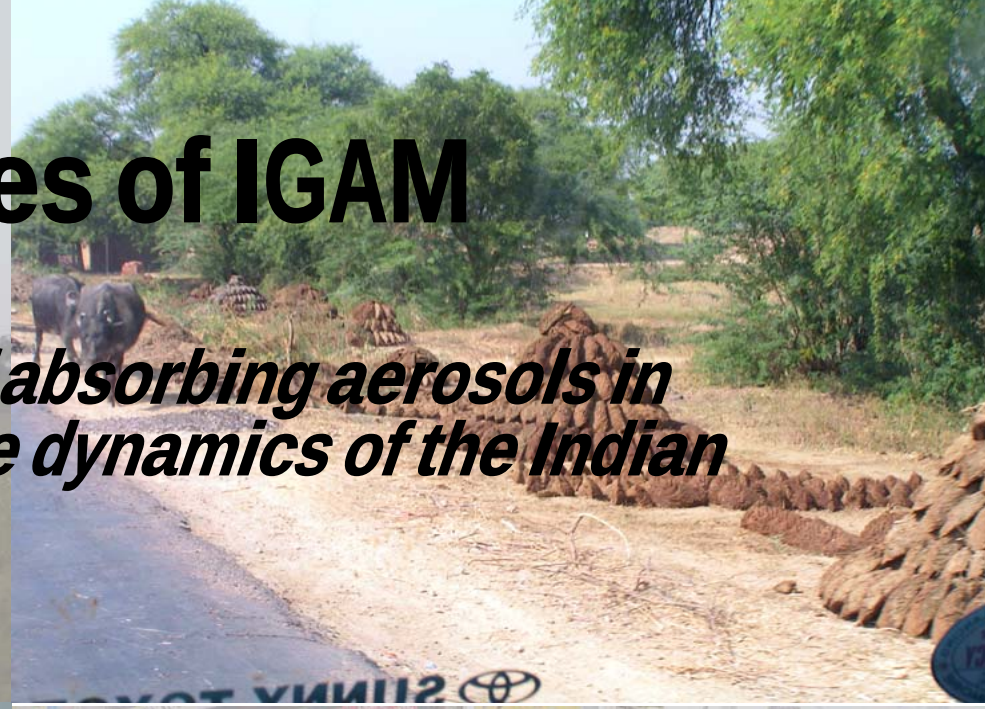
- Anomalous atmospheric heating by absorbing aerosols (dust + BC) stacked up against the southern slopes of Himalayas, cause upper troposphere warming, leading to a reversal of north-south temperature gradient over the elevated high-albedo land surface of the Tibetan Plateau.

- The temperature reversal in April-May acts as a "heat pump", and forced ascent over northern India.

- The anomalous ascent of increasingly warm moist air, leads to an earely onset and subsequent intensifies the Indian monsoon with enhanced rainfall anomaly over northern India and the Bay of Bengal.

- In the long-term (climate change), all aerosols cools the surface, causing spin down of the AHC, and weakening of the monsoon circulation

Objectives of IGAM



- *To determine the role of absorbing aerosols in affecting the water cycle dynamics of the Indian summer monsoon*

Integrated measurements of:

- Aerosol characteristics
- Sources, and transport processes
- Elevated vs. boundary layer; AERONET, ground-based, Lidar, aircraft, satellite…
- Phase-I (April-May, aerosol forcing), Phase-II (May-June, water cycle response)
- Monitoring in surrounding regions, by other Obs. Programs, i.e., ABC, Indian Ocean Monitoring (CLIVAR), Ganges River Basin (GEWEX, and CEOP-II]
- Time-frame : boreal spring and summer of 2006-7