Atmospheric Aerosol: Heating and Cooling Agent of Earth Climate

P. R. Sinha

Balloon Facility @ Tata Institute of Fundamental Research, Hyderabad-500 062

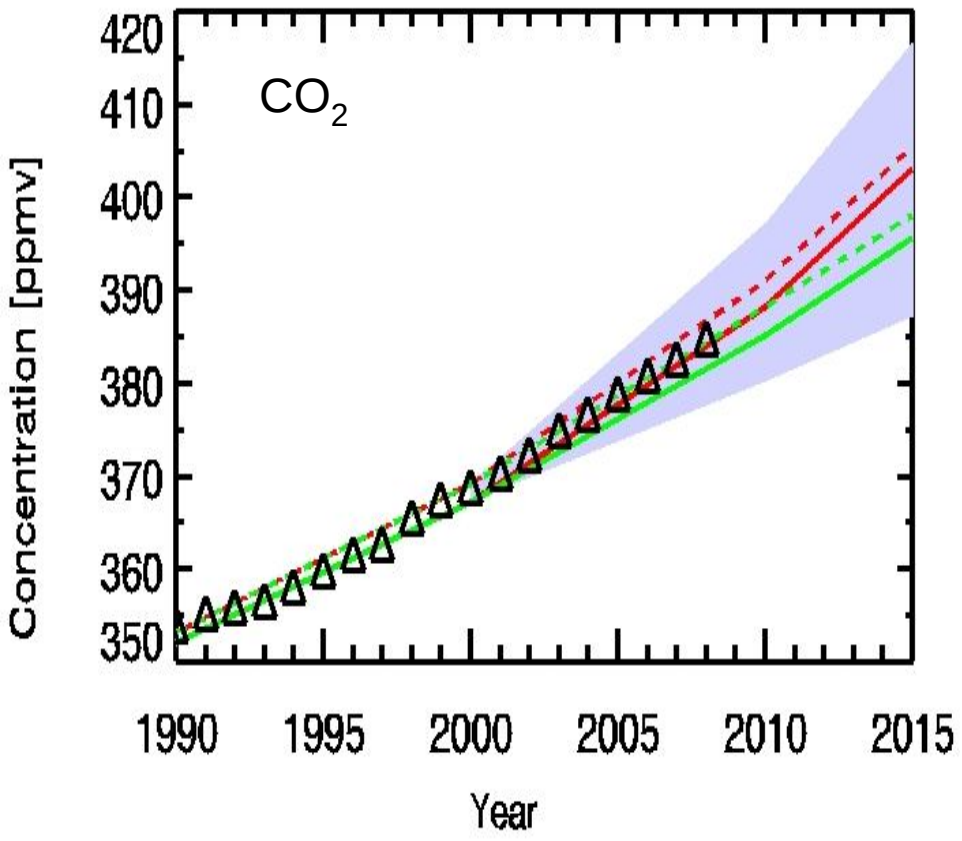
Outline

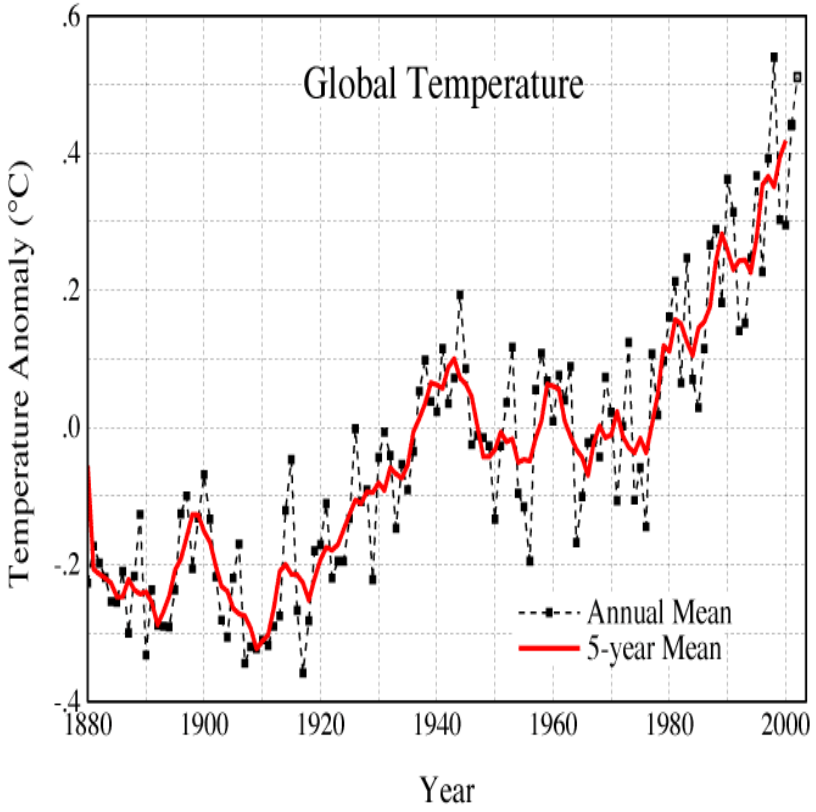
- Global Warming at a Glance
- Atmospheric Aerosol
- Motivation
- Results
  - Characteristics of Aerosol over Hyderabad
  - Characteristics of Aerosol over Bay of Bengal
- Conclusion

Global Warming at a Glance

Global Warming: Earth is running with fever!

Do you know our Climate is Changing?





Source:IPCC

Future Scenario

IPCC predicts an increase in global mean temperature of 4-10°C by 2100

What are Aerosols

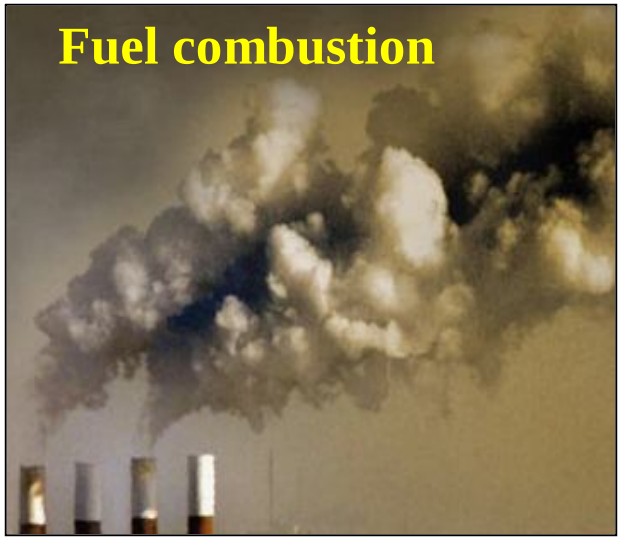
- Aerosols: Micron size particles of solid or liquid phase, dispersed in the atmosphere. They are produced by various physical and dynamical processes, which govern their formation and growth in the in the atmosphere.

- Sources: Natural & Anthropogenic Origin

- **Size:** Running over few nanometers to 100 μm. Depending on the size, aerosols are classified into three categories:

Aitiken nuclei mode ~ 0.001 to 0.1 μm
Accumulation mode ~0.1 – 1.0 μm
Large mode/giant particle > 1.0 μm

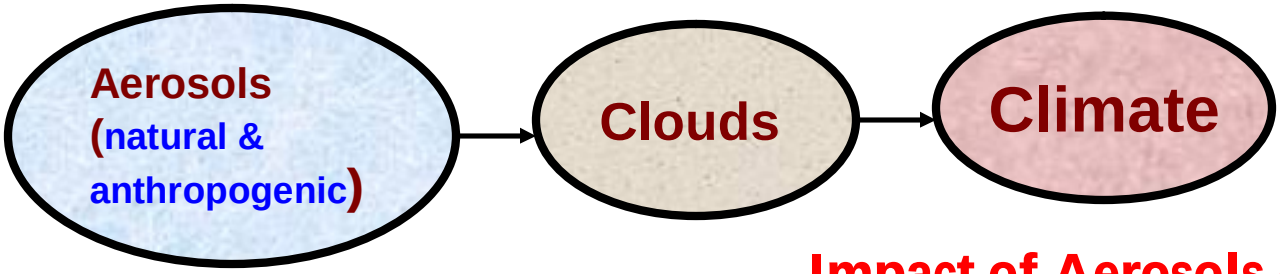
Natural and Anthropogenic Sources



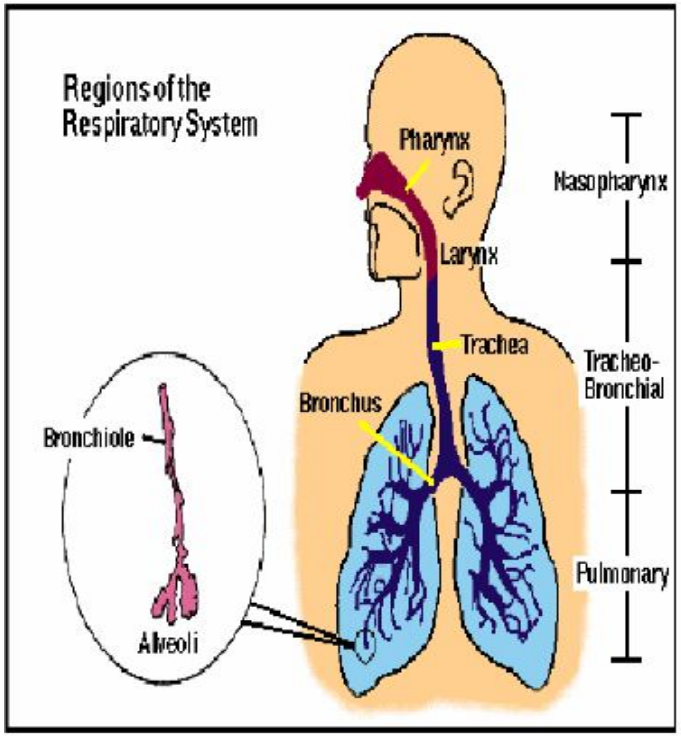
Why Aerosols?

Human health and Planetary health!

Impact of Aerosols on Climate



Impact of Aerosols on Human Health



10μm<r

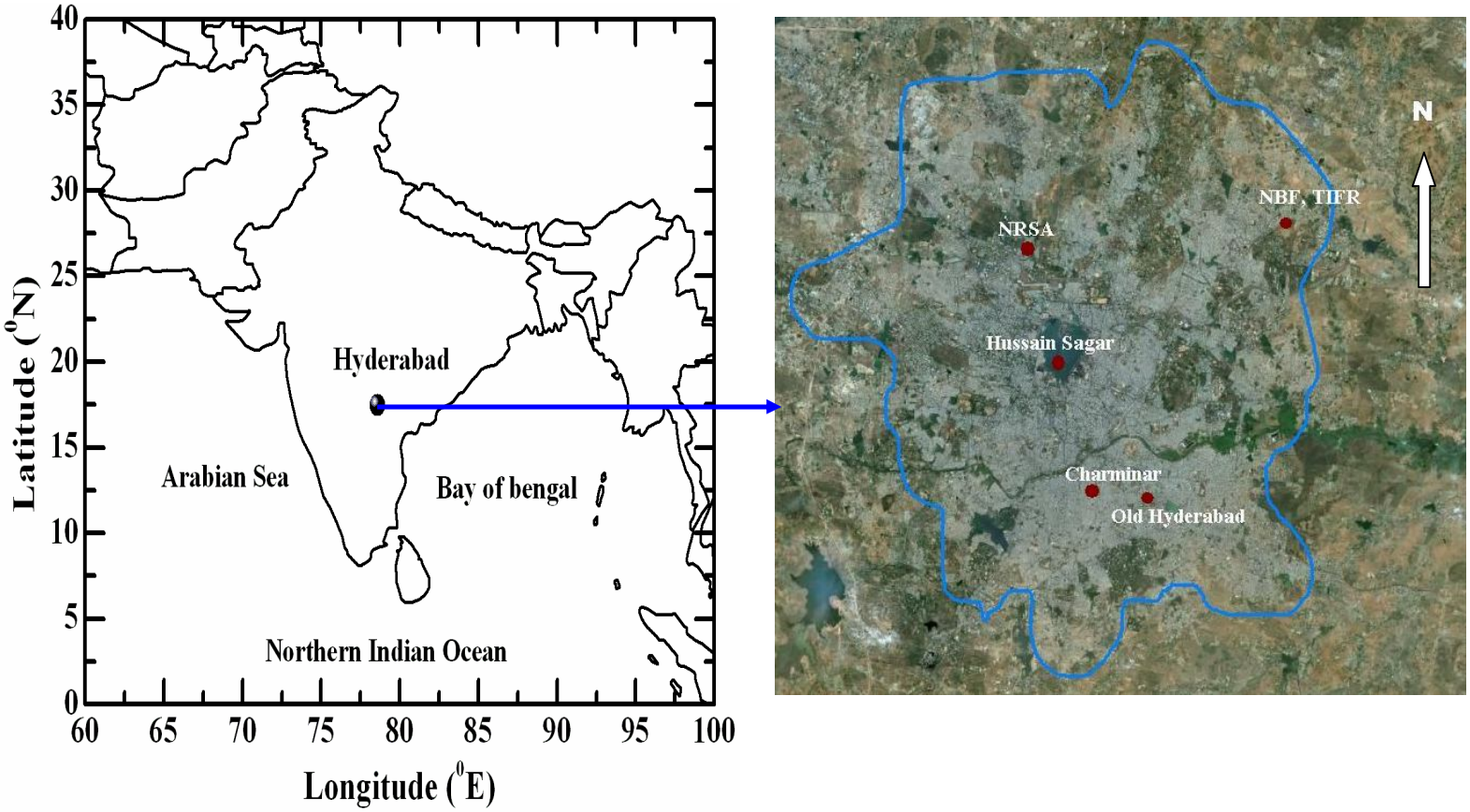
3μm<r<10μm

0.03μm<r<3μm

Motivation

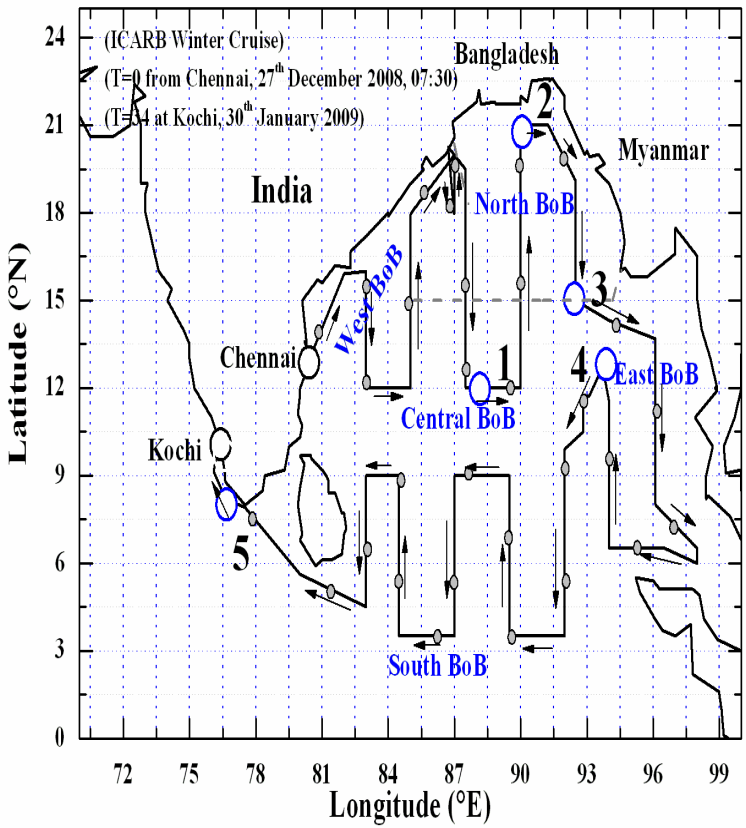
- There exist large uncertainties in anthropogenic aerosol radiative forcing.
- Most of these uncertainties are due to large spatial-temporal variation of aerosol properties, lack of vertically resolved aerosol properties, limited understanding of aerosol direct and indirect effect.
- Urbanization and seasonal variability in air-mass characteristics makes aerosol properties highly variable over Hyderabad with varying effect during different time periods.
- Over Indian region, it is even suggested that aerosols may effect the monsoon circulation through Elevated Heat Pump effect.
- The long range transport and advection of continental air masses form an important component for the observed variability in aerosol characteristics over the ocean region.
- Bay of Bengal plays significant role in the context of Indian monsoon circulation.

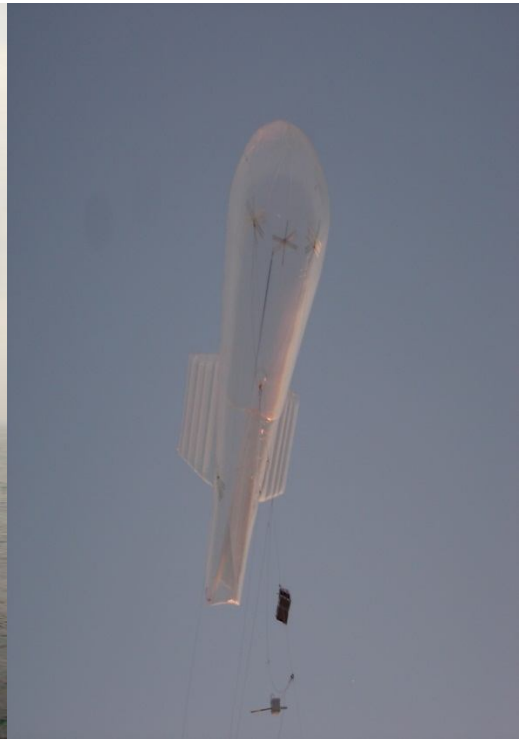
Study Region



Terrain of Peninsular India and site map of the measurement location (Balloon Facility, TIFR) at the outskirts of Hyderabad

The cruise track of Sagar Kanya-254 in the Bay of Bengal during W-ICARB



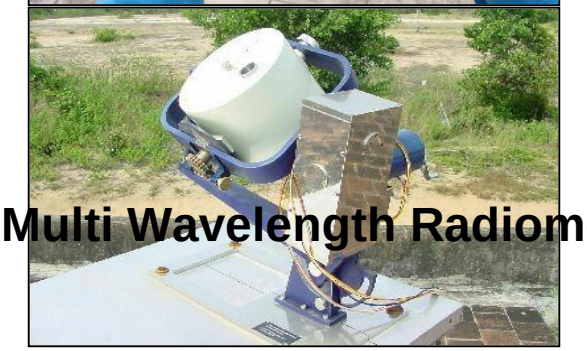


The arrow shows the track of the ship while the gray circles show the position of the ship at 10:30 LST for each day.

Hoisting of the Kytoon on board the ship. Optical Particle Counter (OPC) is seen tied to the belly strings.

List of Instruments

Sun Photometer



Multi Wavelength Radiometer

Aethalometer

LIDAR

Optical Particle Counter

Quartz Crystal Microbalance

Trace Gases Analyzers
(O_3 NOx, CO, SO_2)

Radiosonde +Ozonesonde

Basic Parameters of Aerosol

1. **Particulate Matter (PM_2)**

Mass of the aerosol particles having diameter less than 2μm
(It is an index of air pollution)

2. Aerosol Optical Depth (AOD) : Column aerosol concentration

$\tau_\lambda = \beta\lambda^{-\alpha}$

τ_λ = **AOD**

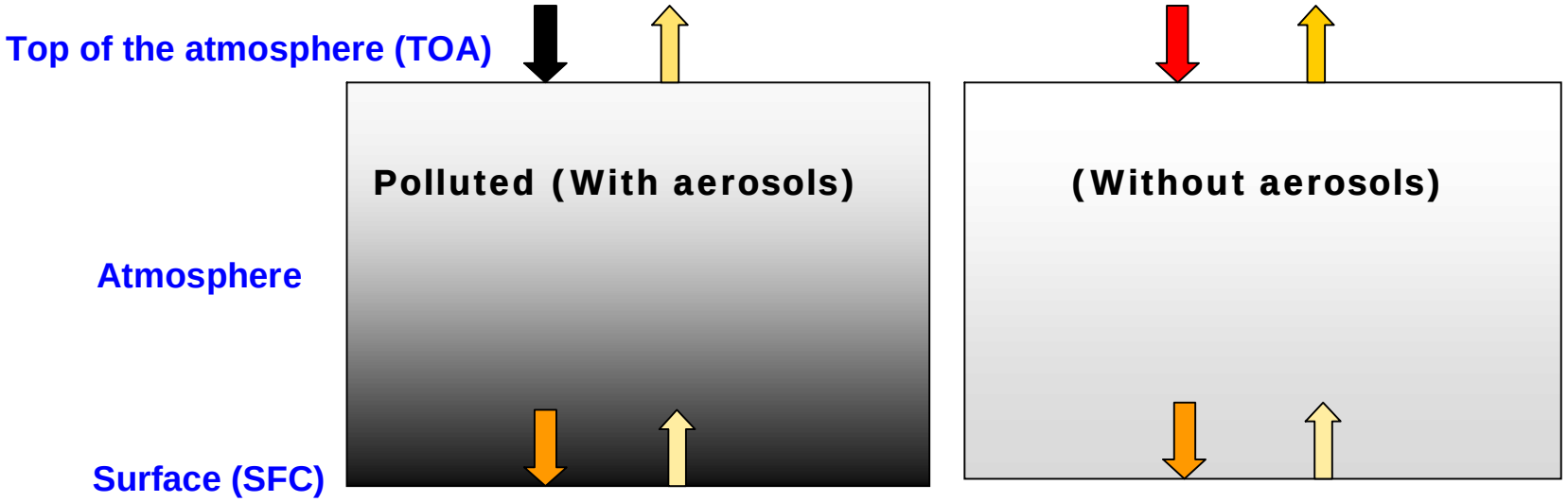
Angstrom exponent (α) >1 Fine mode, submicron aerosol particles
α<1 coarse mode, supermicron aerosol particles

3. Curvature

$\ln\tau_\lambda = \alpha_2(\ln\lambda)^2 + \alpha_1\ln\lambda + \alpha_o$

α_2 <0 fine mode, submicron aerosol particles
α_2 >0 coarse mode, supermicron aerosol particles

4. **Aerosol Radiative Forcing (Energy imbalance of the earth system)**



Net flux at the TOA (or SFC)= total downward flux – total upward flux

Aerosol radiative forcing (F) = $(\text{Net flux})_{\text{without aerosols}} - (\text{Net flux})_{\text{with aerosols}}$

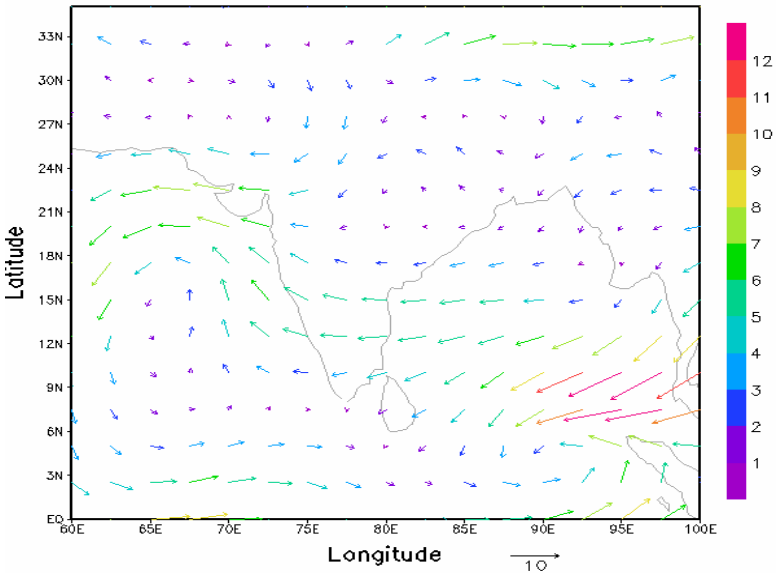
$$F_{ATM} = F_{TOA} - F_{SFC}$$

–ve forcing (cooling of earth-atmosphere system)

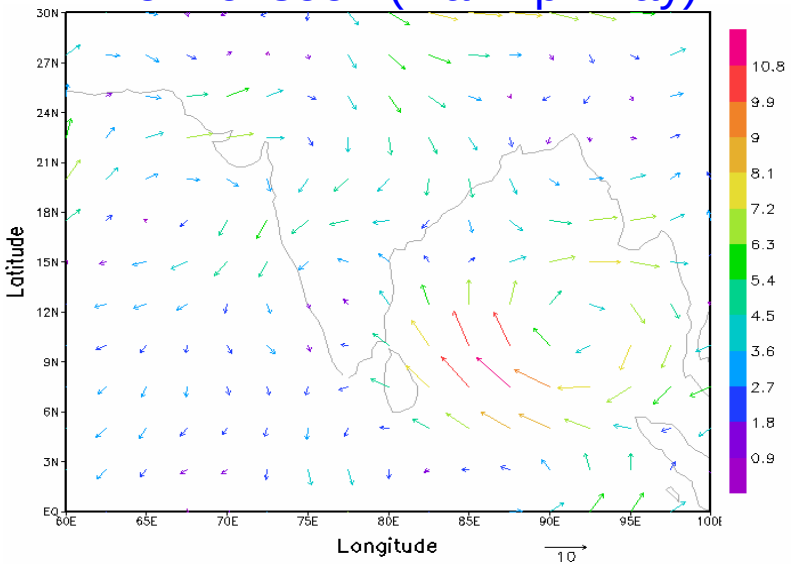
+ve forcing (warming of the earth-atmosphere system)

Synoptic Wind

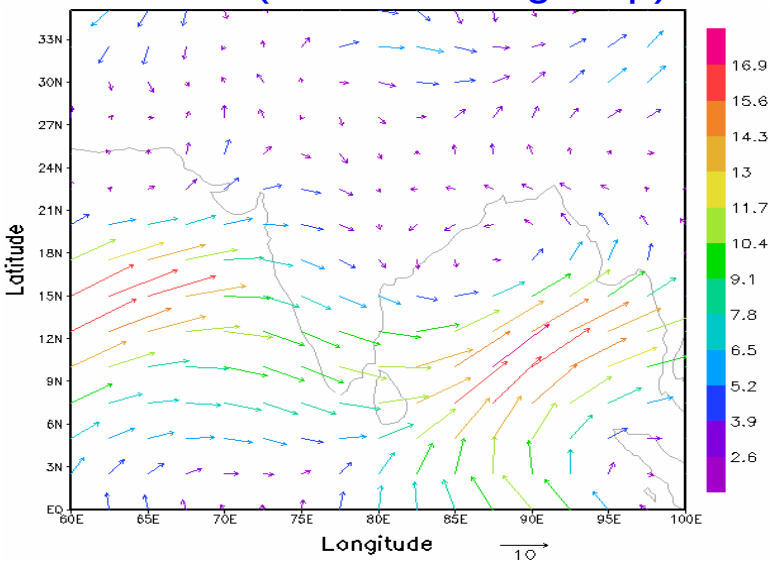
Winter (Dec-Jan-Feb)



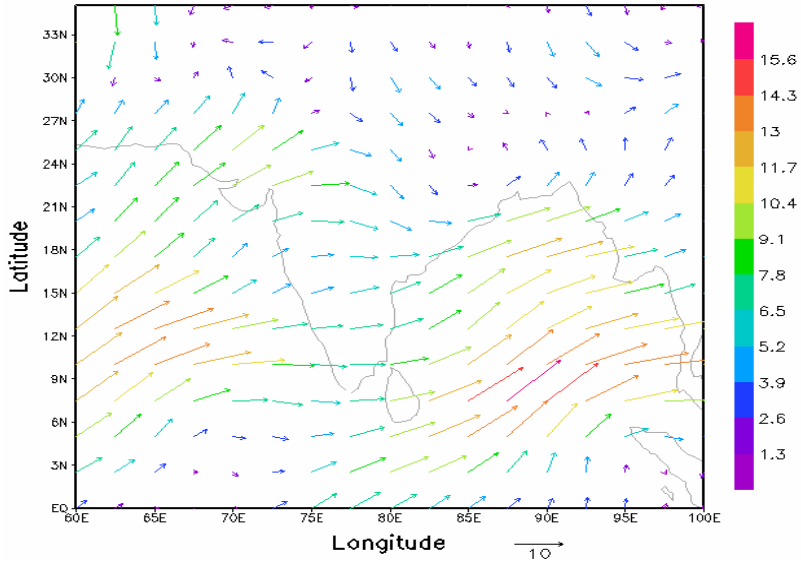
Pre-Monsoon (Mar-Apr-May)



Mosoon (June-Jul-Aug-Sep)

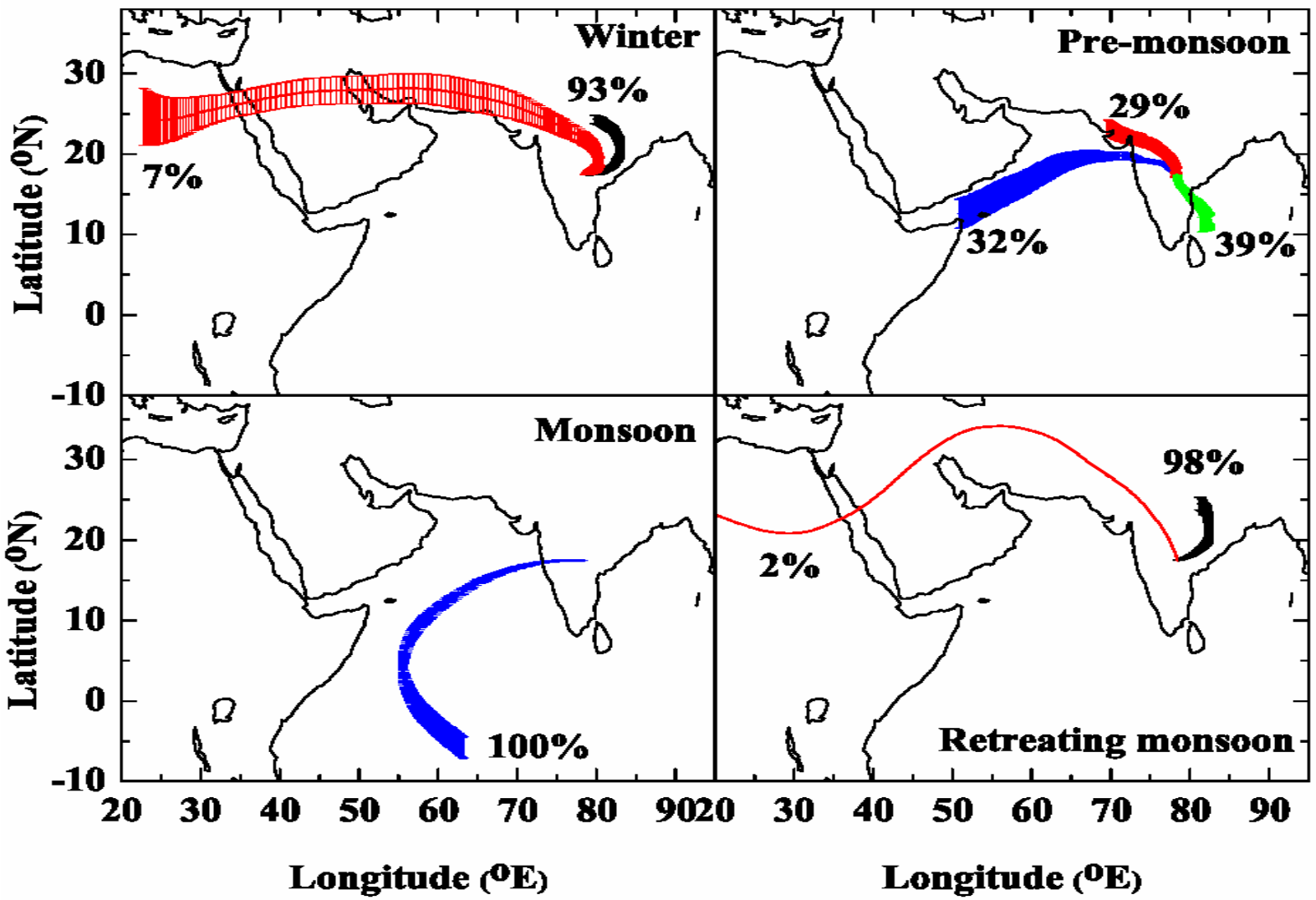


Post-Monsoon (Oct-Nov)



Role of Long Range Transport

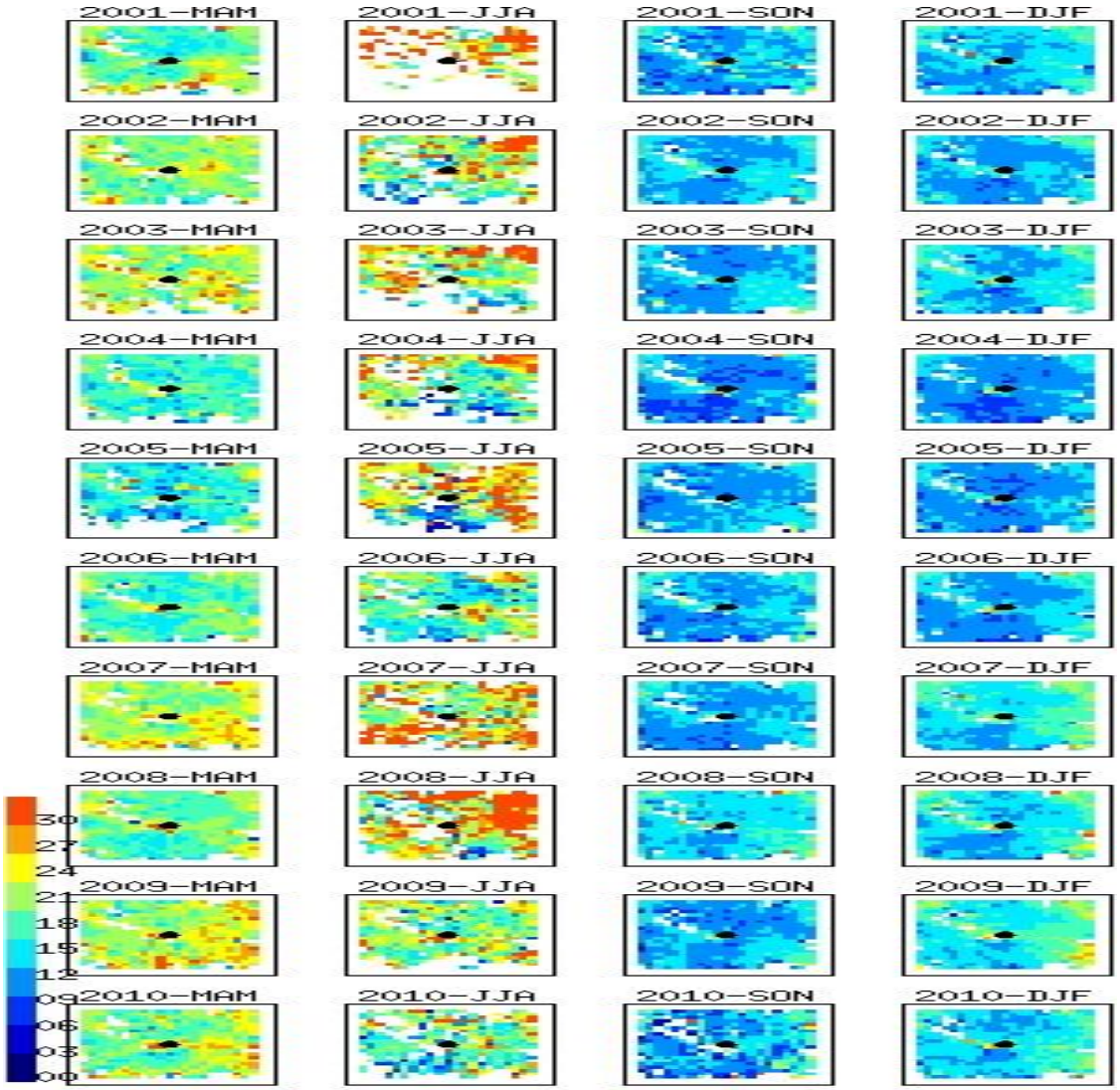
Seven-day air mass back trajectory at 2000m agl over Hyderabad



Spatial Distribution of Surface Aerosol

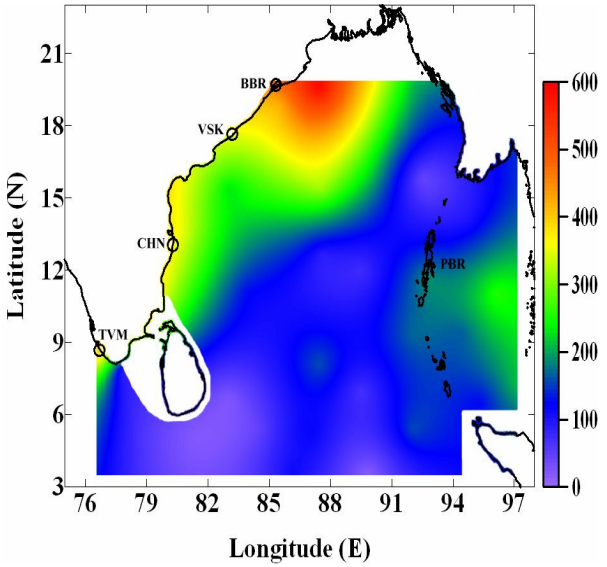
Hyderabad

PM_2 derived from Terra-MODIS AOD

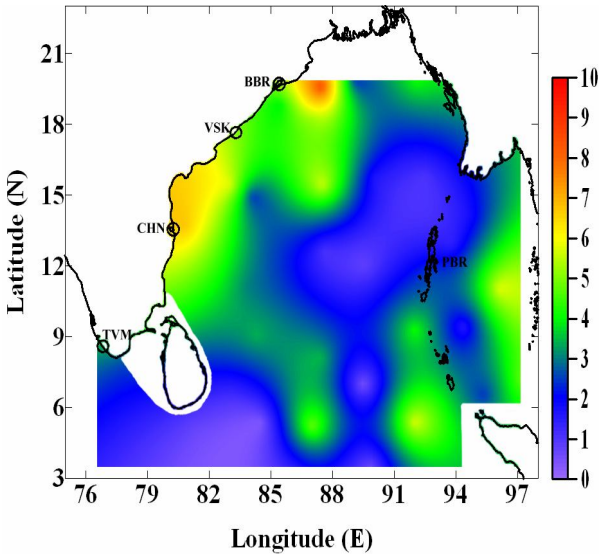


Bay of Bengal

Submicron (#/cm³); r<1µm

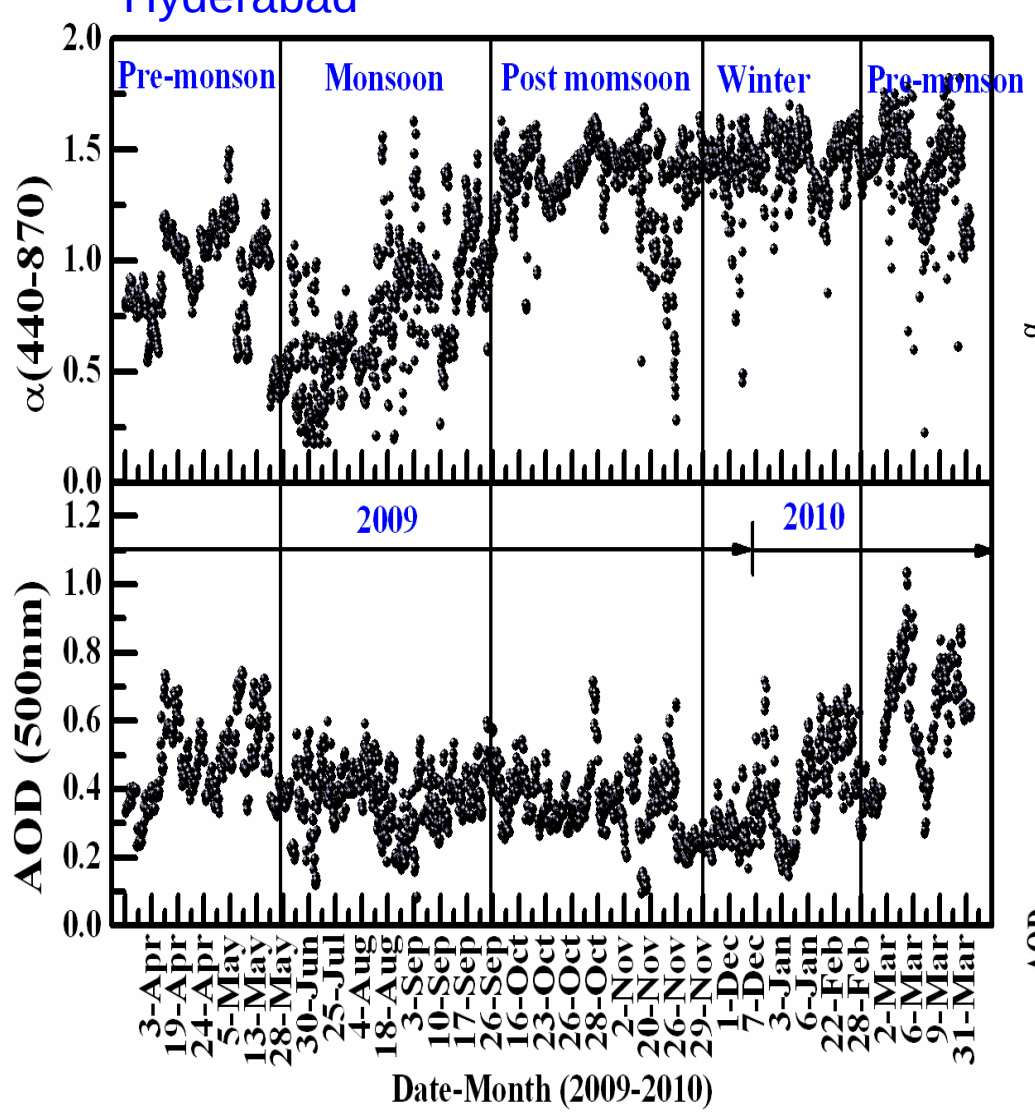


Supermicron(#/cm³); r>1µm

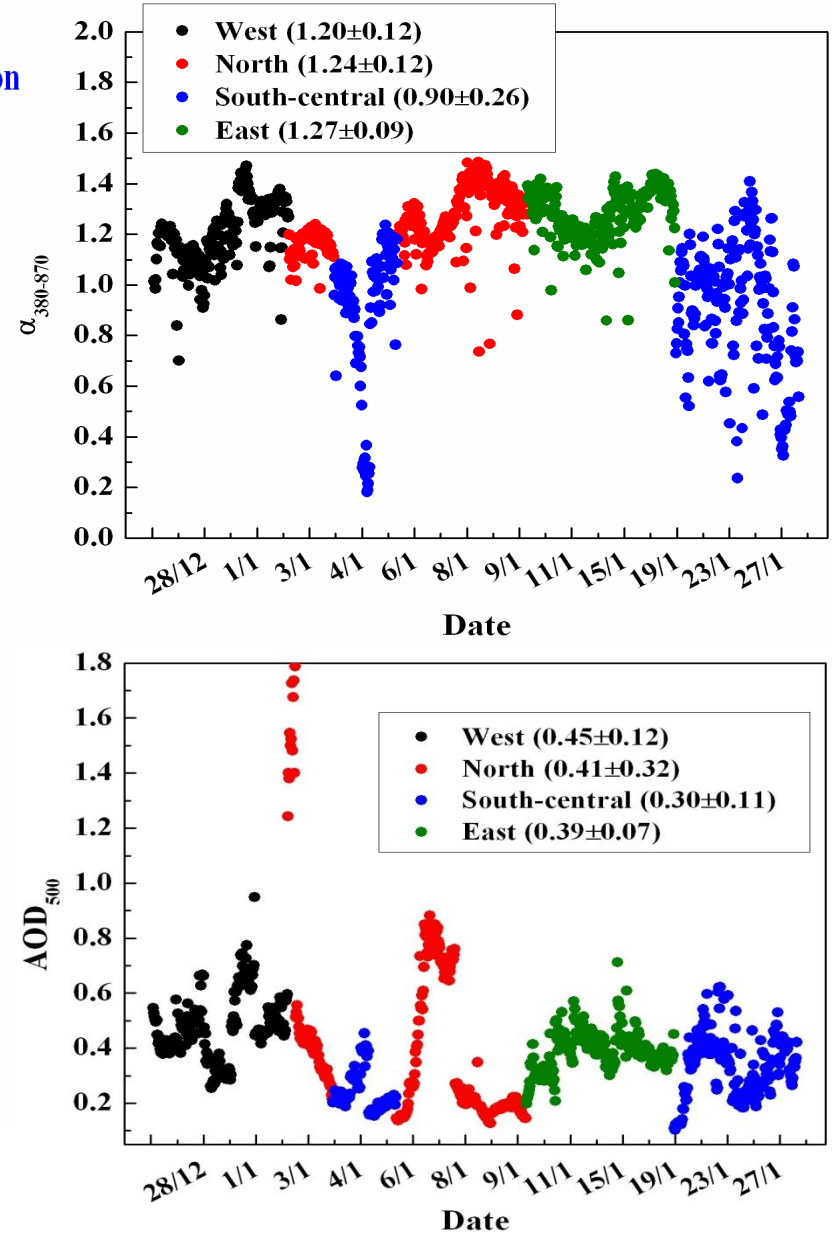


Daily variation of Columnar Aerosol loading and their types

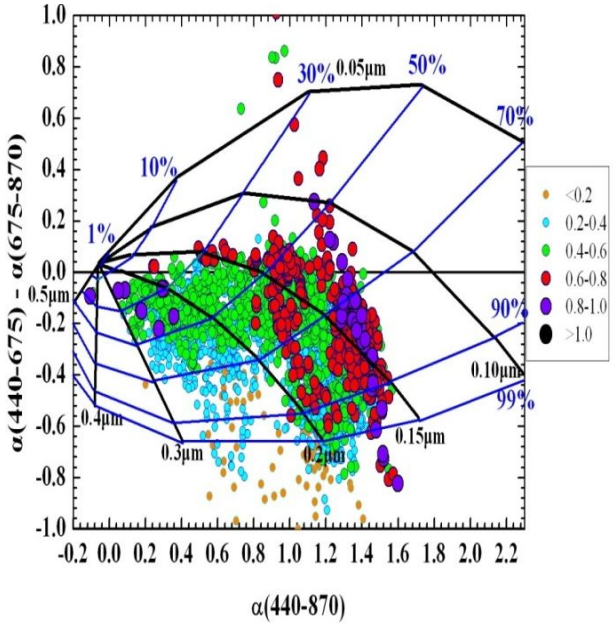
Hyderabad

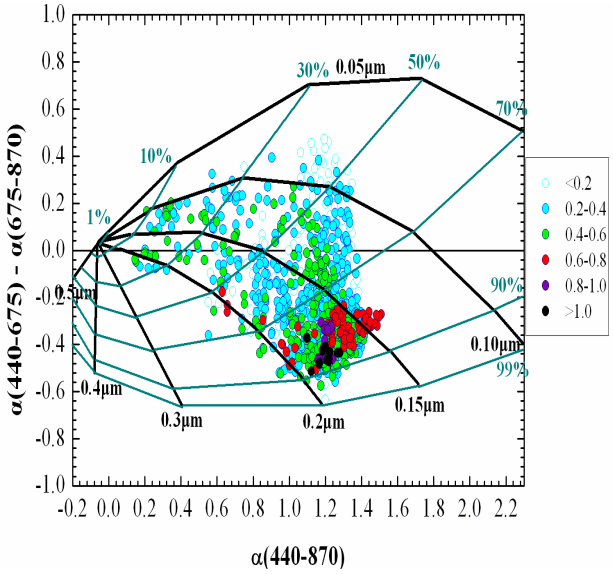


Bay of Bengal



Major Aerosol Modification Processes over Land and Ocean





Hyderabad

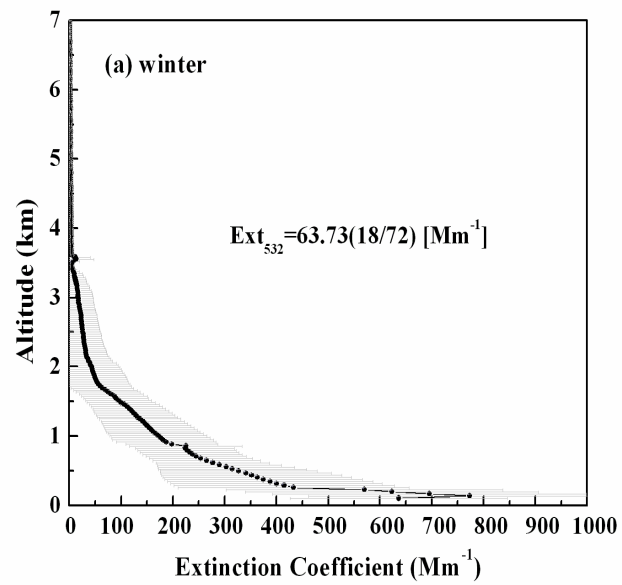
Indian Monsoon Season	Modification Processes
Winter	coagulation and condensation
Pre-monsoon	gas to particle conversion
Monsoon	humidification
Post-monsoon	coagulation and condensation

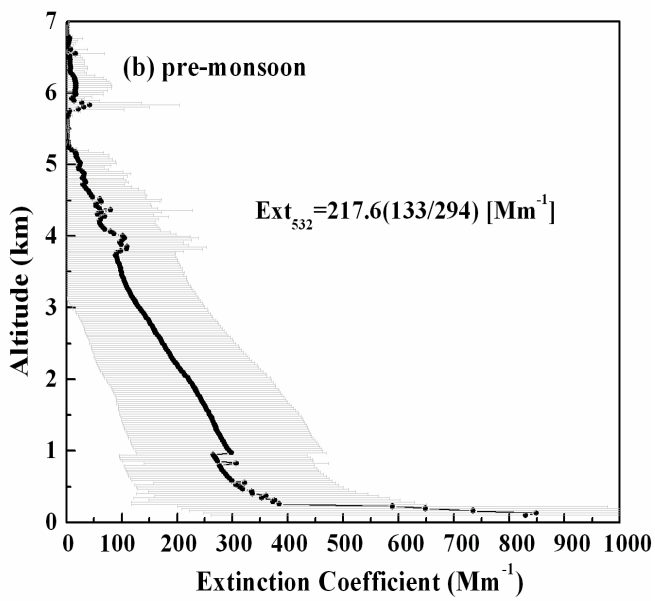
Bay of Bengal (BoB)

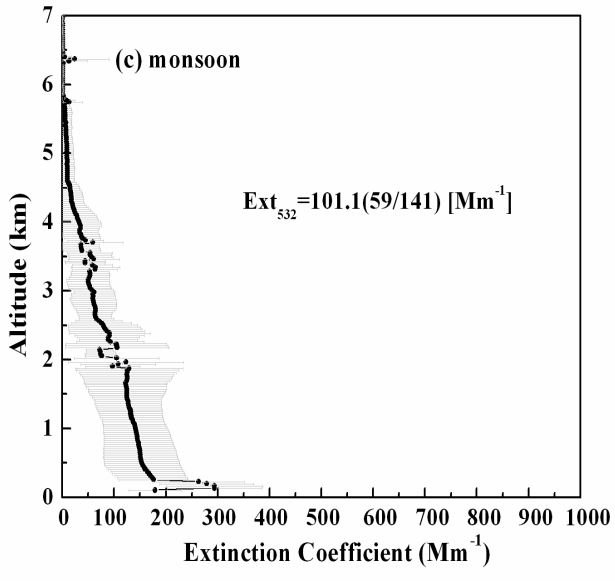
Sub region of BoB	Modification Processes
West BoB	gas to particle conversion
North BoB	Aging/humidification/coagulation
South-Central BoB	not conspicuous
East BoB	coagulation, aging and hydration

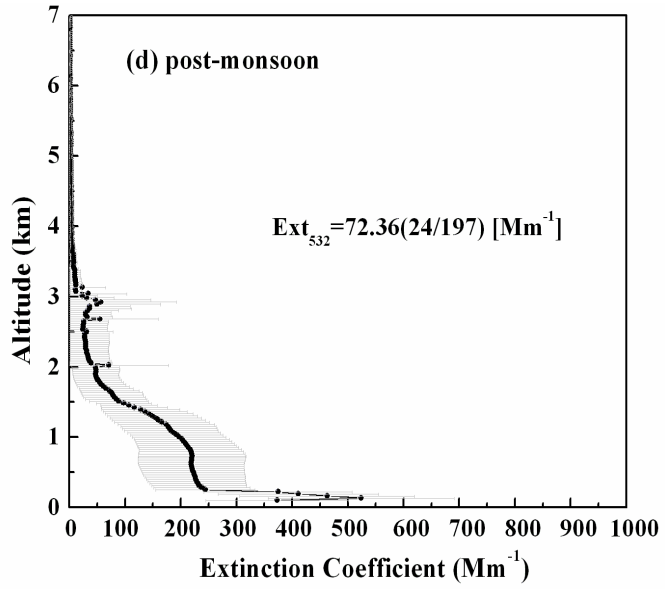
Vertical Profile of Aerosol

Hyderabad



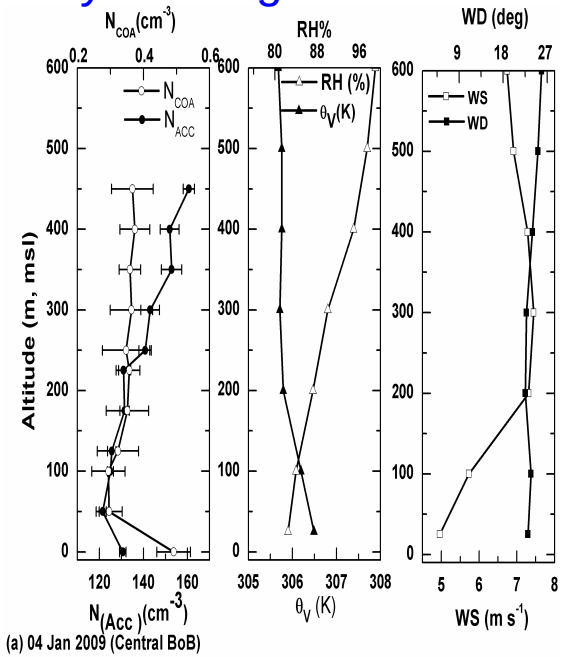




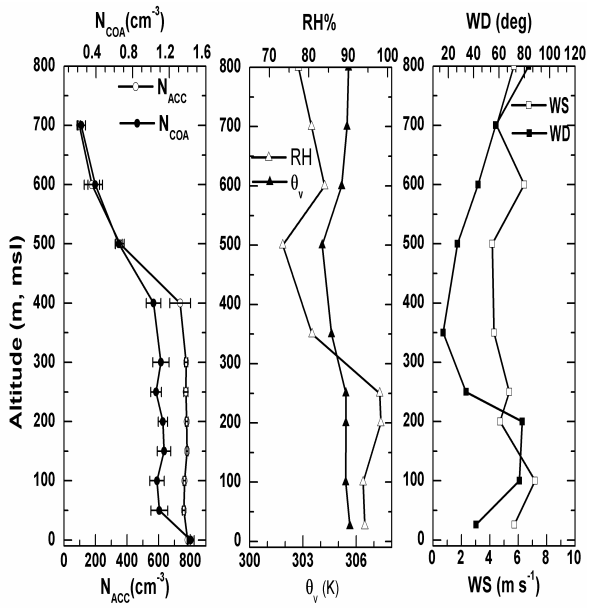


Vertical Inhomogenity in Aerosol Number Concentration

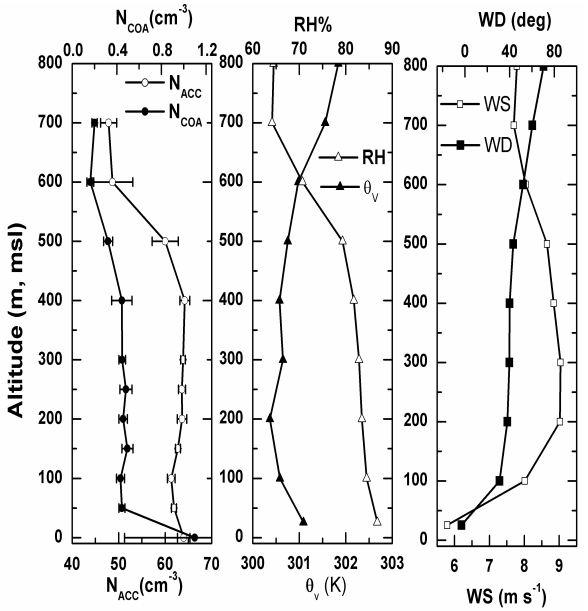
Bay of Bengal



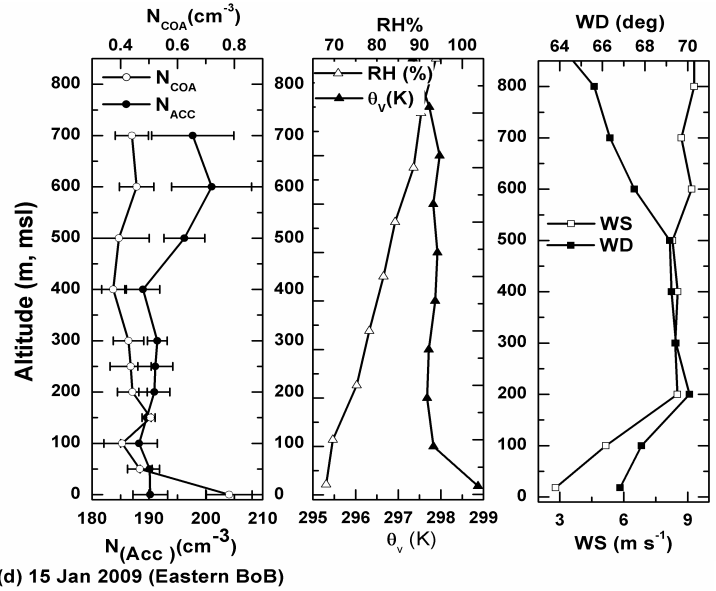
(a) 04 Jan 2009 (Central BoB)



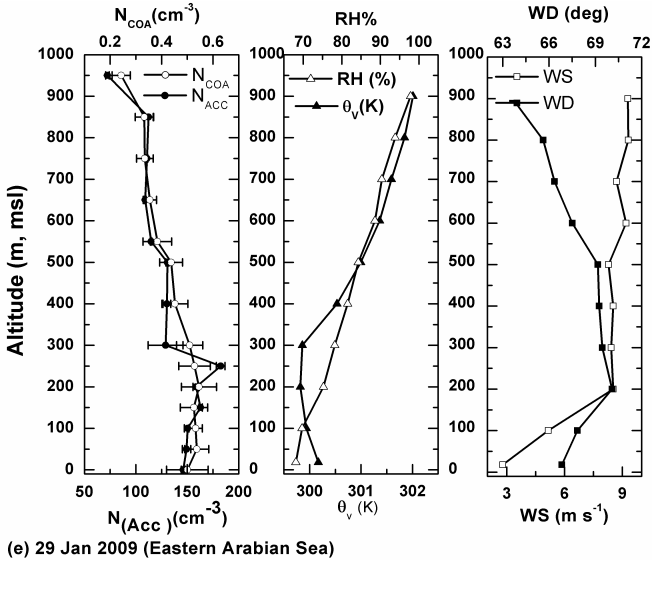
(b) 07 Jan 2009 (Northern BoB)



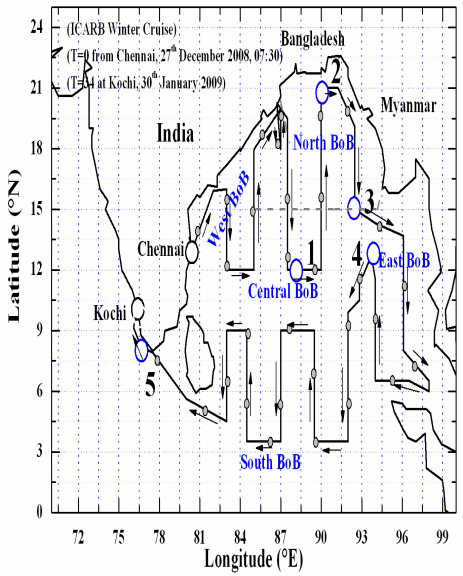
(c) 09 Jan 2009 (North Eastern BoB)



(d) 15 Jan 2009 (Eastern BoB)

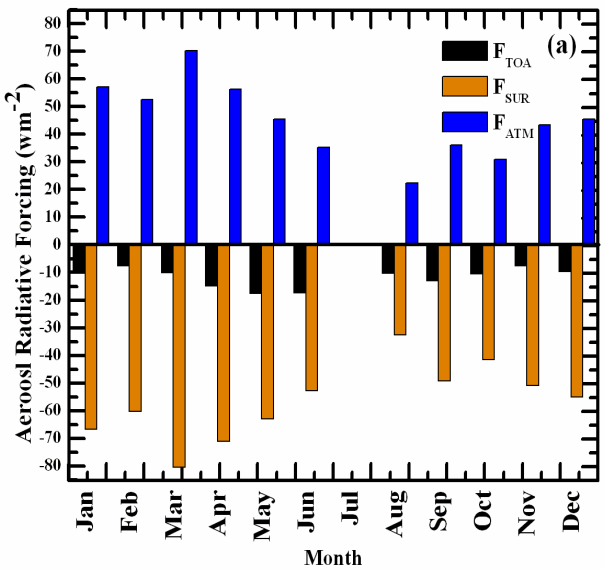


(e) 29 Jan 2009 (Eastern Arabian Sea)

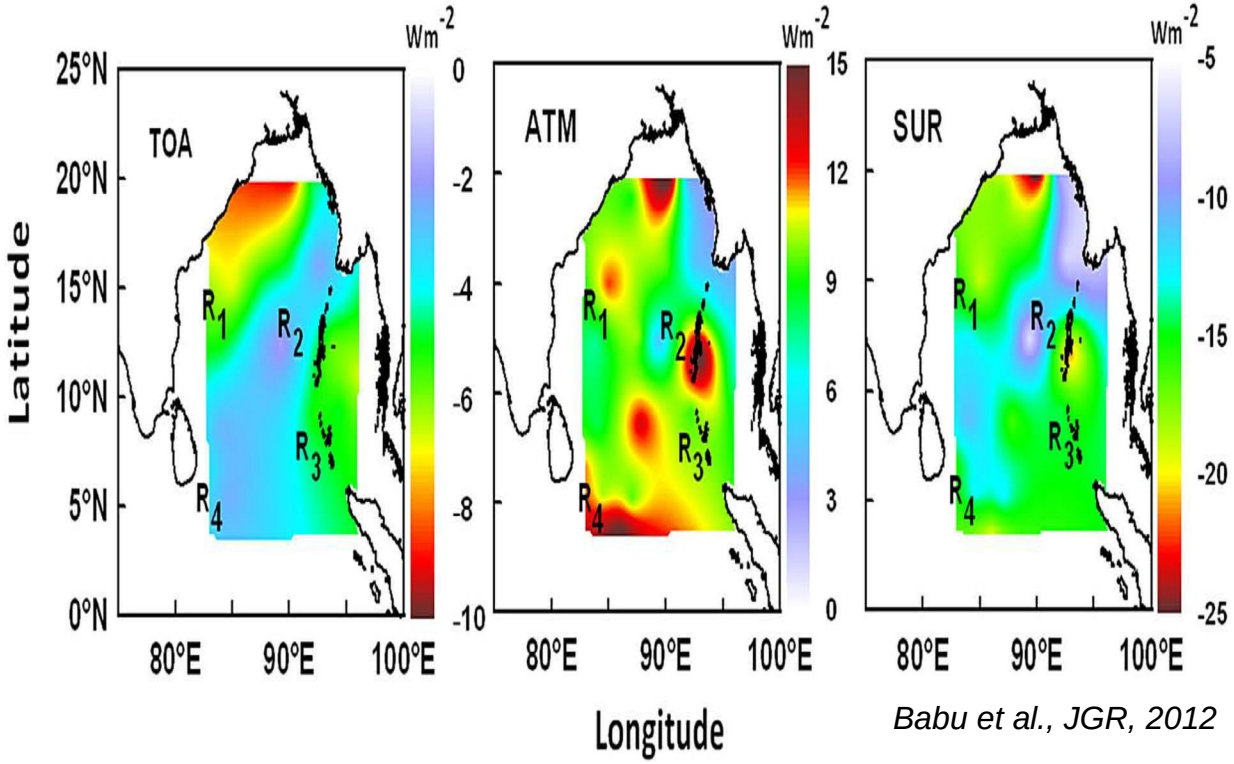


Aerosol Radiative Forcing

Hyderabad



Bay of Bengal



Babu et al., JGR, 2012

Incorporation of large spatial heterogeneity in aerosol radiative forcing in regional climate models is called for to increase the accuracy of impact assessment.

Altitude Distribution of BC and Possible Impacts on Atmospheric Stability

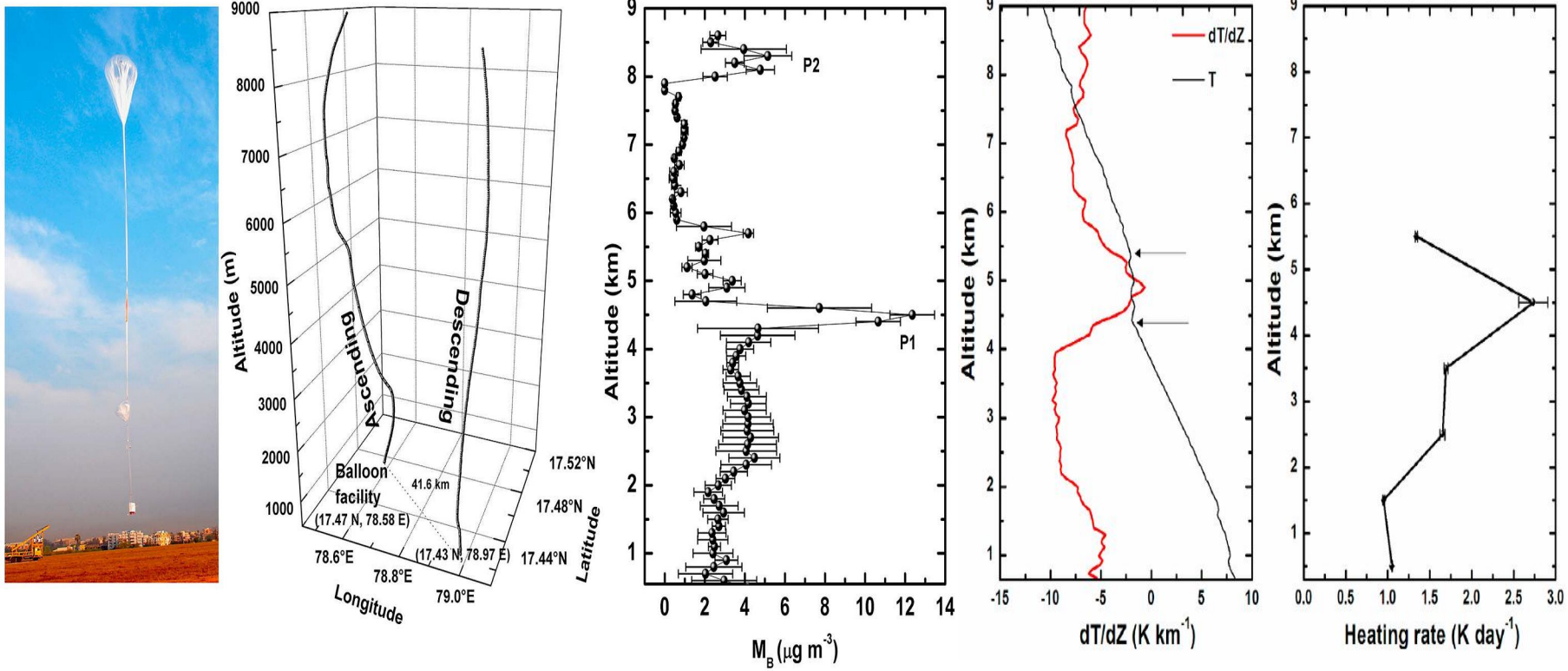
1. Vertical lofting from the surface by the strong thermal convection over the land

2. Local confinement by convectively stable layers, trapped between unstable layers and inversions

3. Long□range transport by change in advection patterns and

4. Other possible local source of elevated BC

Hyderabad



Do BC layers build “their own homes” up in the atmosphere?

Impact of Aerosols in Indian Monsoon Circulation

1. Surface Demining Effect

Haze Plumes (ABCs) over NIO

The thick haze layer, consisting of dust, BC, sulfate, fly ash aerosols [referred to as Atmospheric Brown Clouds (ABCs)], is transported from South Asia towards the India Ocean. It causes significant perturbations in the regional radiation budget with large reductions in the solar insolation at the ocean surface. The reduction of sunlight cuts the evaporation rates which further suppress convection from the ocean surface leading to reduced moisture transport towards the subcontinent during the peak monsoon season. This mechanism suggests the weakening of monsoon circulation and reduction of monsoon rainfall with the future possibility of frequent droughts.

2. Elevated Heat Pump Effect

Large amounts of anthropogenic aerosols mixed with BC and dust form a thick aerosol layer during pre-monsoon season, over Indian sub-continent and able to heat the lower and middle atmosphere. The enhanced aerosol solar absorption creates a temperature anomaly which amplifies the overturning of the meridional circulation and thus causes to draw in more moisture from the Indian Ocean. This mechanism has been hypothesized in the advancement and intensification of the early summer monsoon.

3. Aerosol-Cloud Interaction (Aerosol Indirect Effect)

Sulfate aerosol acts as cloud condensation nuclei and enhance the precipitation, whereas soot and dust aerosol suppress precipitation.

Conclusion

- Significant variation in the aerosol distribution, columnar loading and large fraction of submicron aerosol with variety of modification processes indicates that large heterogeneity in aerosol sources and their strength over land and ocean.

- The majority of the aerosols are confined within the boundary layer with large fine mode fraction over land and ocean during winter.

- Elevated absorbing type aerosol (BC) layers increases the atmosphere stability and could likely impact the cirrus clouds. The direct radiative effects of these aerosols could influence the evolution of the active break cycles of Indian monsoon through modification of the spatial distribution of the heating. This could be one of the potential causes for the transition of several strong and relatively long breaks to active monsoon condition.

- The aerosols over Hyderabad can significantly heat the atmosphere.

- Large spatial heterogeneity in radiative forcing persists even over a small oceanic region like BOB, being caused by distinct advection processes. Incorporation of these in regional climate models is called for to increase the accuracy of impact assessment.

Thank you for your kind attention