
به نام خدا

Monitoring of Dust Optical Characteristics Using Remote Sensing Instruments

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This Presentation covers

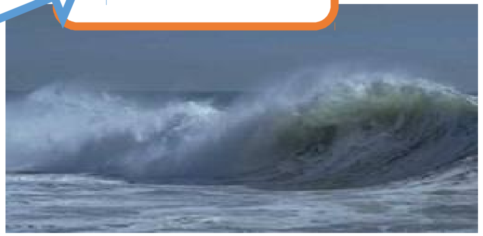
- Introduction
- Impacts of dust storms
- Satellite remote sensing
- Remote sensing instruments
- Aerosol optical properties
- Satellite & ground data validation
- Variation in Aerosol Characteristics during Dust

What are aerosols and Dust?

Atmospheric aerosol is a mixture of liquid and solid particles, with radii varying from a few nm to 100 μm.

Sources

Natural

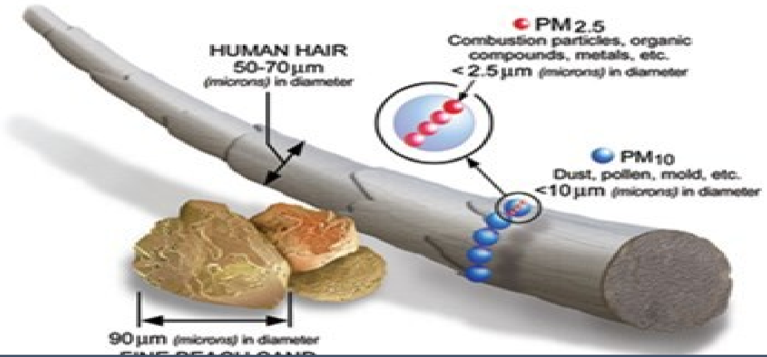


Anthropogenic

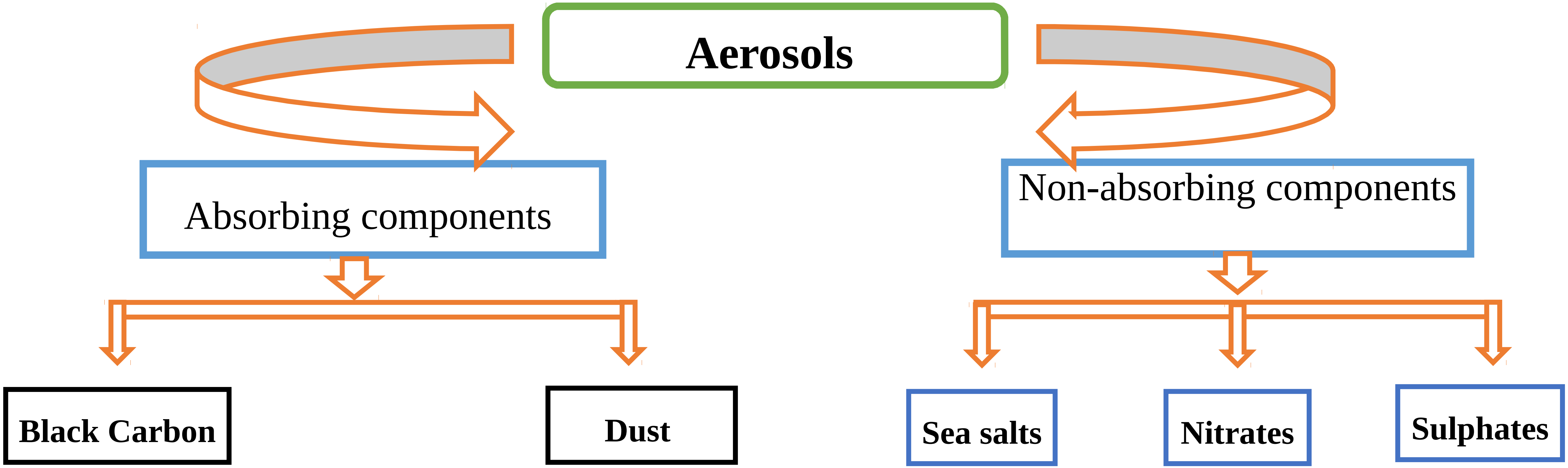
Sizes

PM 10 Coarse

PM 2.5 Fine



Classification of Atmospheric Aerosols



Aerosol Types

Dust aerosols

- Coarse particles probably consist of a mixture of quartz and clay minerals produced in arid regions

Biomass burning aerosols

- Fine particles mainly consist of black carbon and organic aerosols probably produced from natural or manmade fires

Urban/industrial aerosols

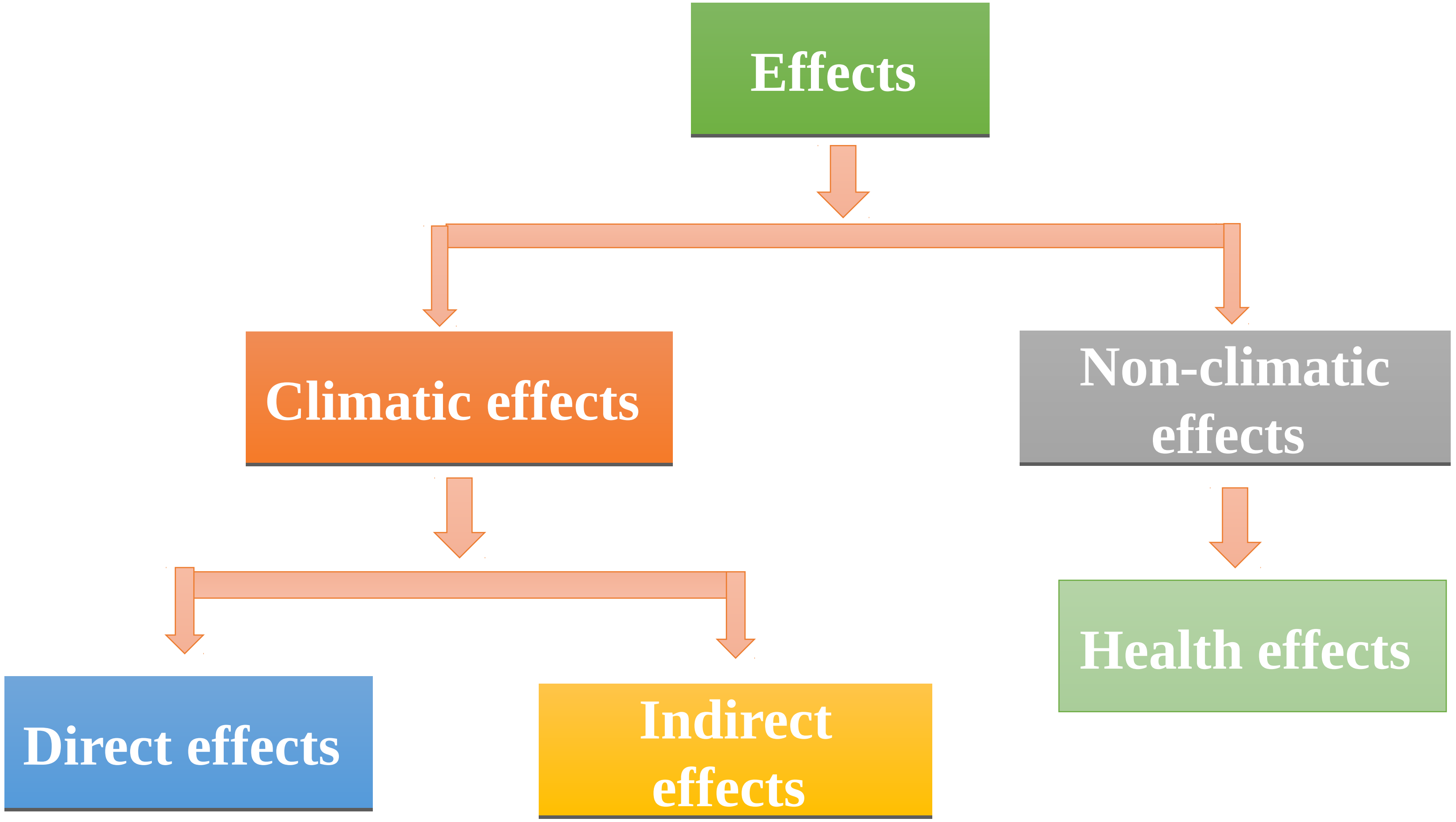
- Fine particles mainly consist of anthropogenic aerosols produced in urban and industrial regions

Dust characteristics

- Dust storms occasionally reach up to 1km | 5km | 10km **height**, and are as thick as 100m | 2km | 5km

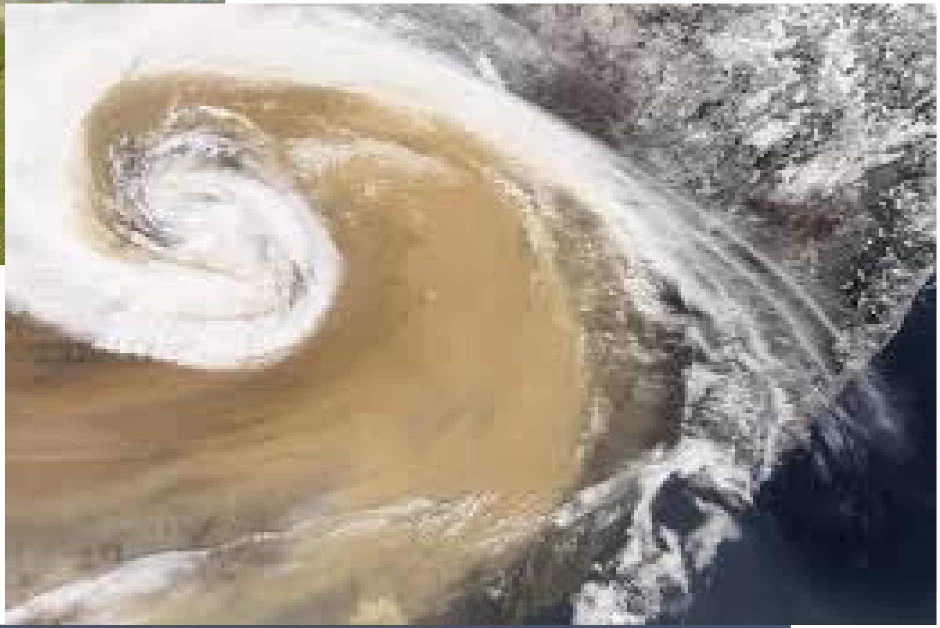
- Over land, dust optical depth is typically around 0.1 | 0.5 | 1 or 2 | 5 for storms, in the visible range.

- Dust absorbs and scatters **infrared** radiation in the **Mie | Rayleigh | optical** region


Effects
Climatic effects
Non-climatic effects
Direct effects
Indirect effects
Health effects

Sources of Dust Emissions: 3 major types

Natural desert sources



❖ World's Largest Deserts

❖ Impacts of dust storm

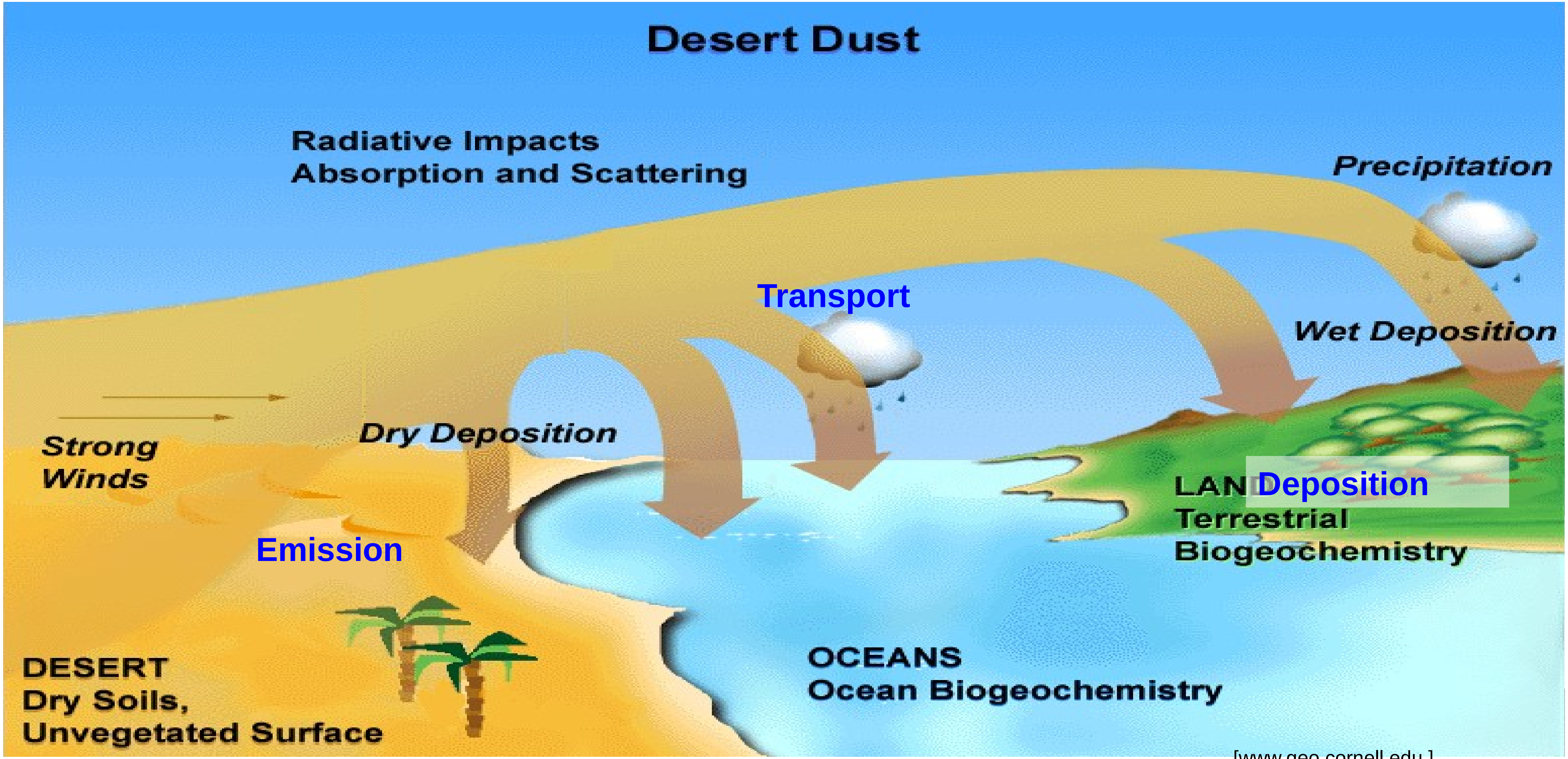
Dust Storm

Health
Dust storm carries bacteria and spores from fungi Which are in the size respirable can worsen breathing problems

Climate
Dust can alter the Earth's atmosphere through direct and indirect forcing

Biogeochemical processes
Dust injects nutrients, such as iron, into marine ecosystems

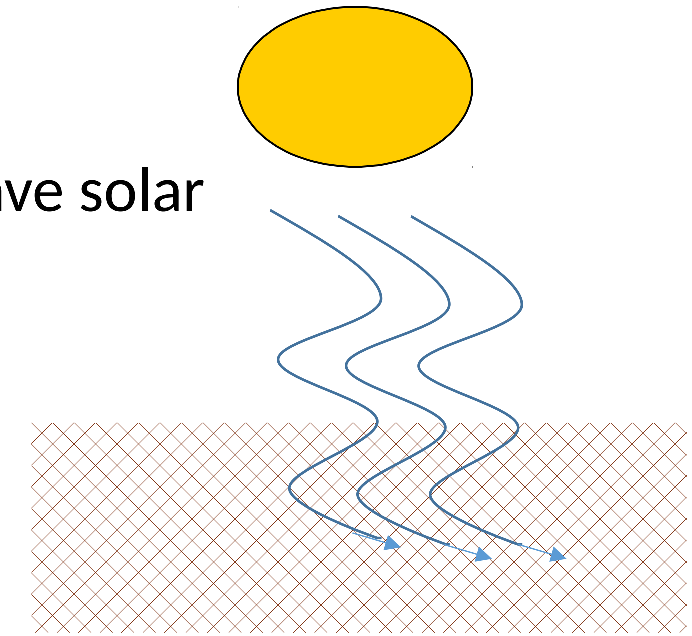
❖ Atmospheric Dust Cycle



[www.geo.cornell.edu]

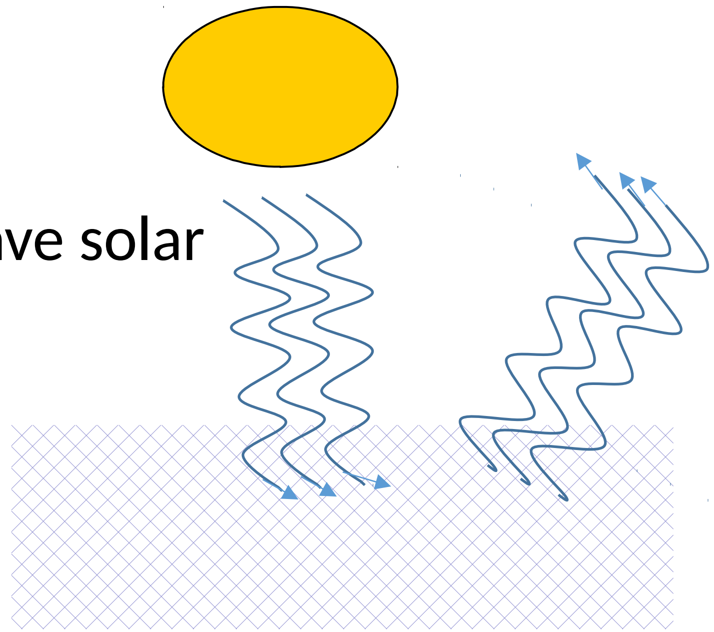
Direct radiative forcing by dust aerosols (Direct effect)

Absorb longwave solar radiation



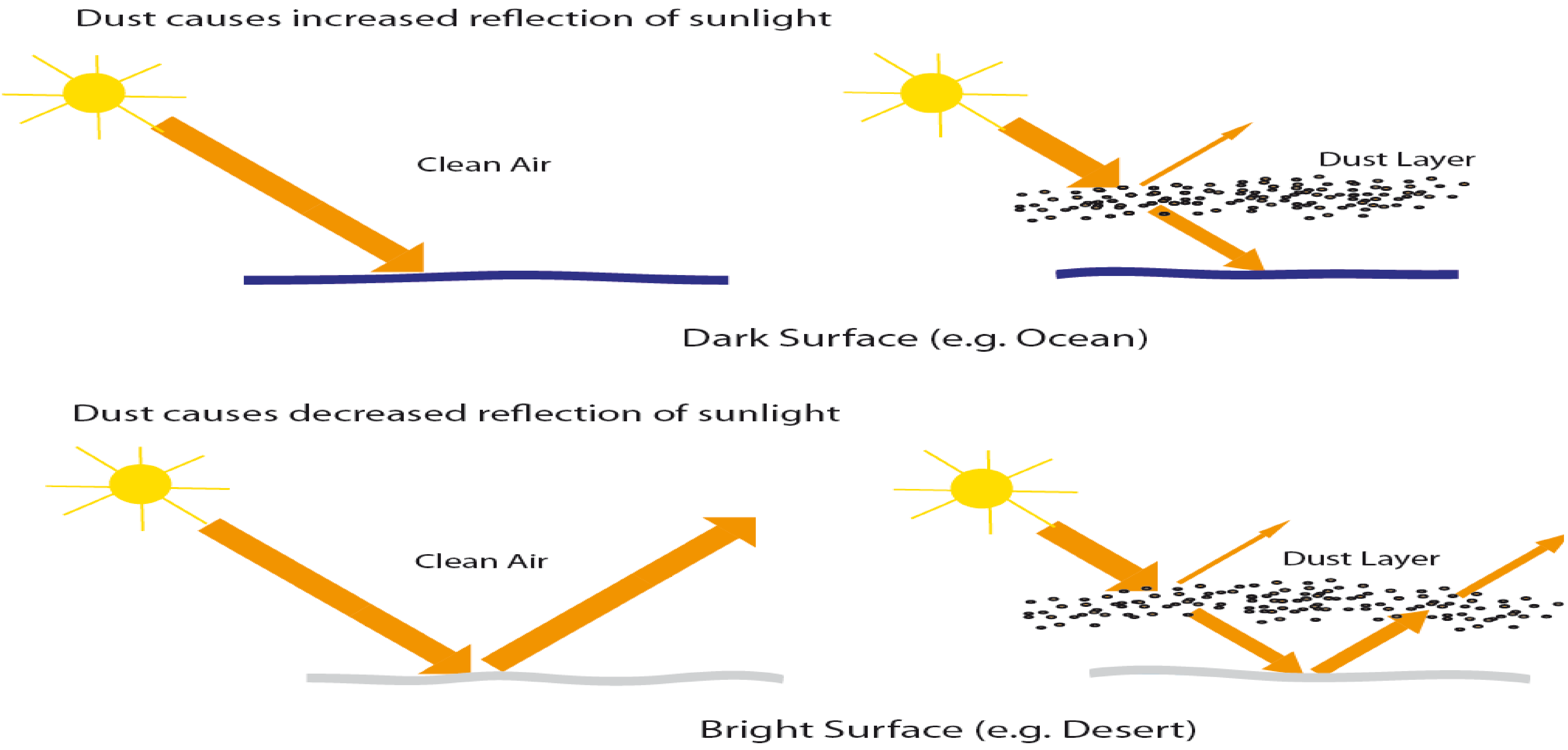
Solar radiation absorbed (Warming)

Scatter shortwave solar radiation



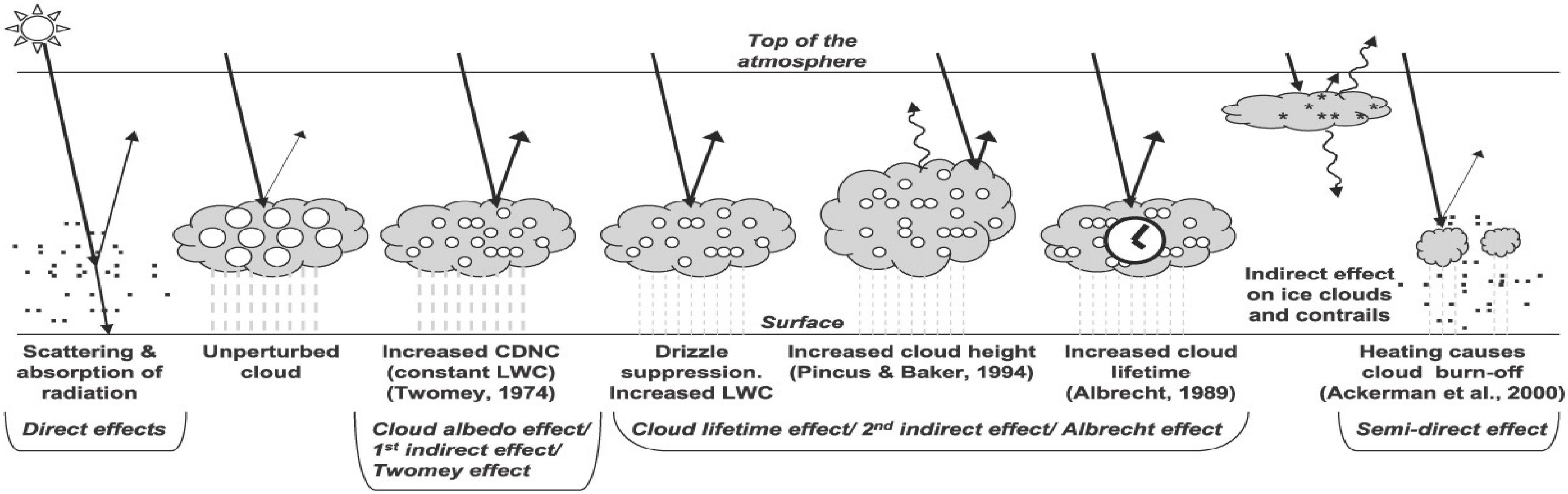
Solar radiation scattered to space (Cooling)

Impacts of dust storm



Aerosol – Cloud Interactions

Indirect effect: aerosol-cloud effect



IPCC report, 2007

❖ Impacts of aerosol on cloud

How can humans affect clouds?

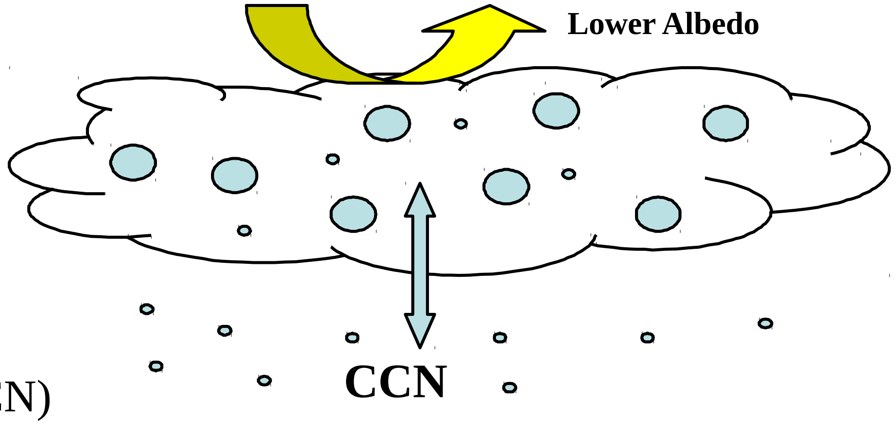
By changing CCN; cloud properties are a *strong* function of their concentration.

This phenomenon is known as aerosol indirect effect.

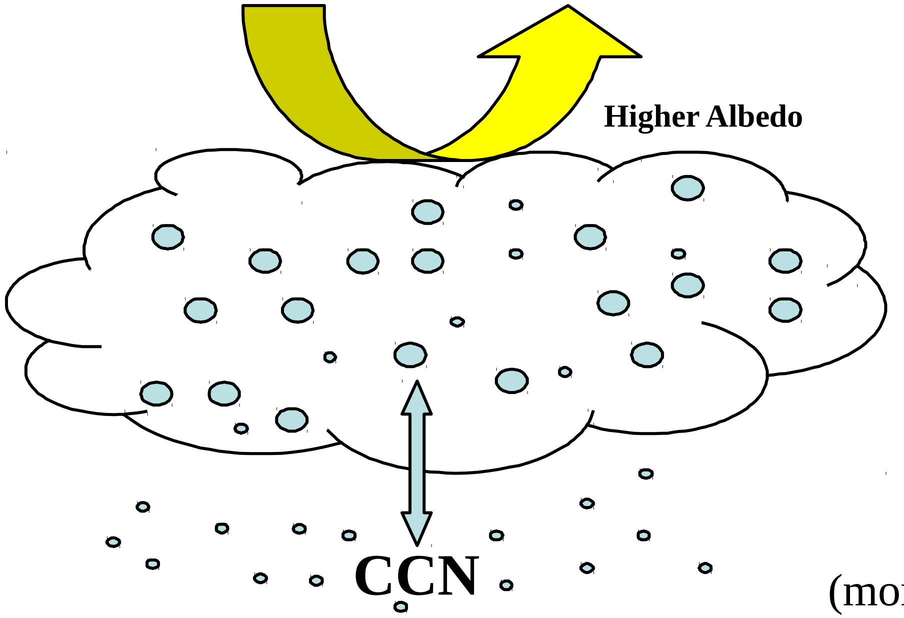
The aerosol indirect effect can lead to ***climatic cooling*** by:

- Increasing cloud reflectivity (albedo)
- Increasing cloud lifetime & coverage.

(few CCN)



Clean Environment

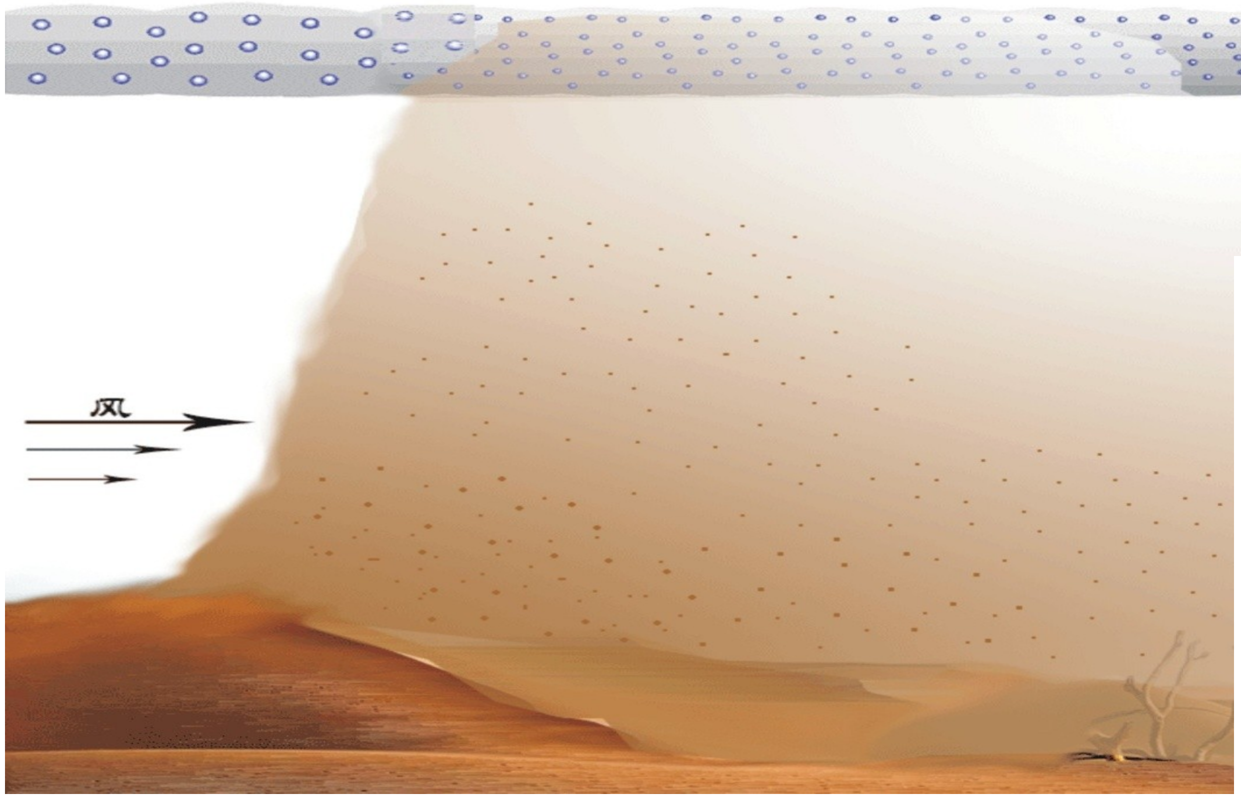


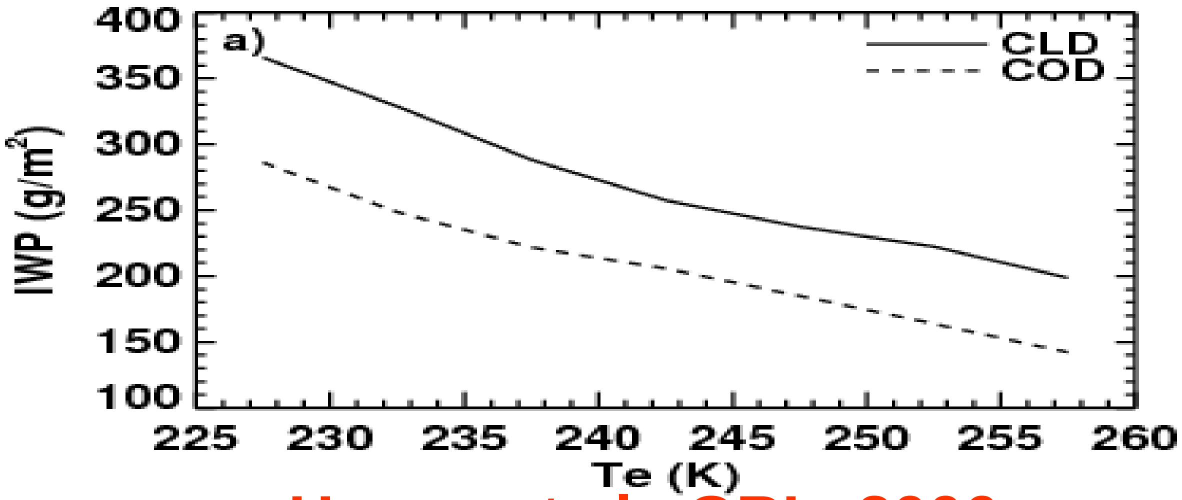
(more CCN)

Polluted Environment

Climatic Effects of Aerosols

Dust indirect effect was evidenced by observation

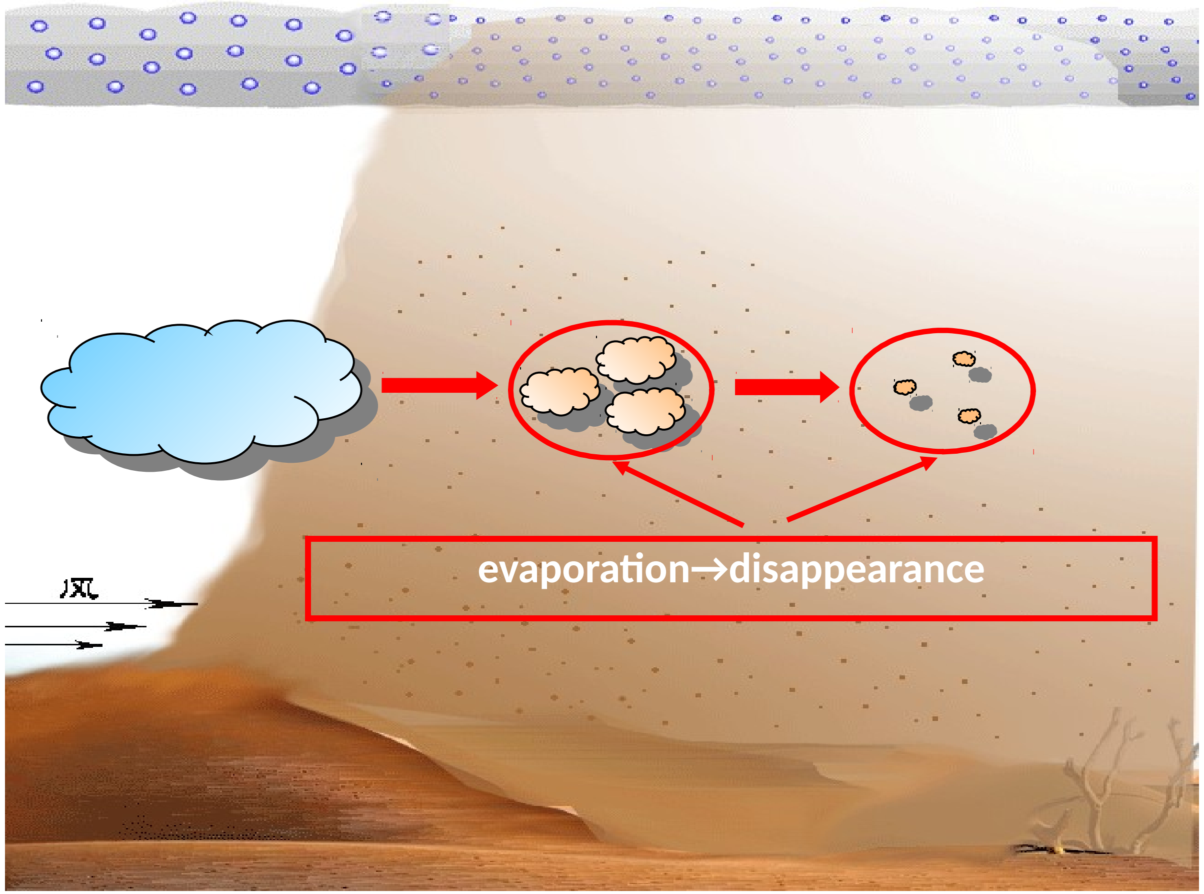


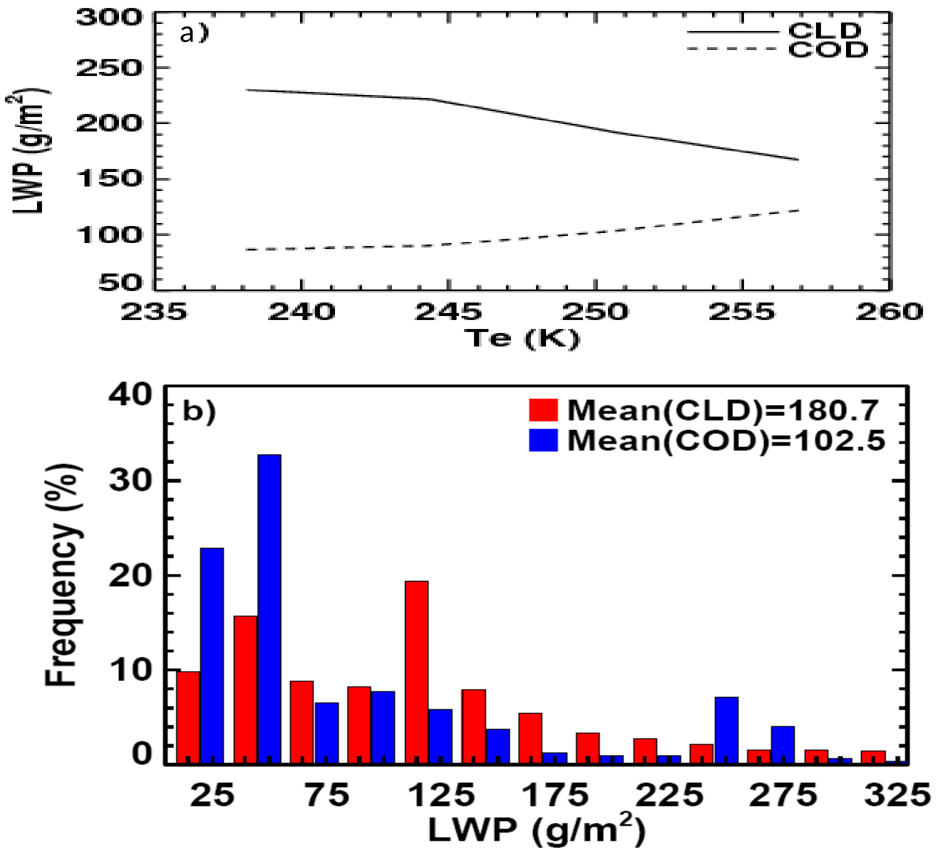


Huang et al., GRL, 2006a

Dust Aerosol, as Cloud condensation nuclei (CCN), can change cloud microphysical property, cloud fraction and cloud lifetime, thus can indirectly influence the radiation budget of the earth-atmosphere system.

Semi-direct effect may contribute to arid climate

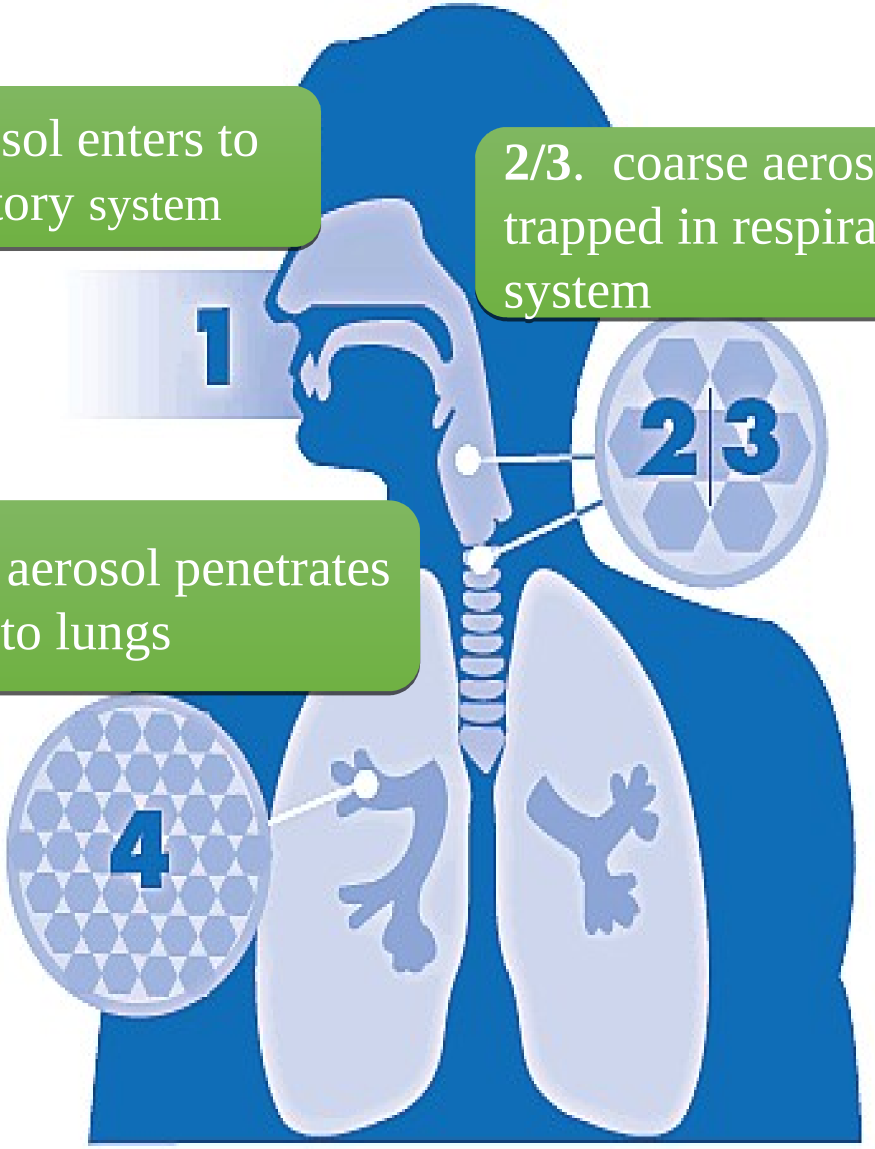




Huang et al., GRL, 2006b

Dust Aerosols' semi-direct effect can increase droplet evaporation, reduce liquid water path by 49.8%, lead to less precipitation.

Human Health Effect of Aerosols



1. Aerosol enters to respiratory system

2/3. coarse aerosol trapped in respiratory system

4. Fine aerosol penetrates deep into lungs

Asthma

Pulmonary inflammation

Hay fever

Eyes infection

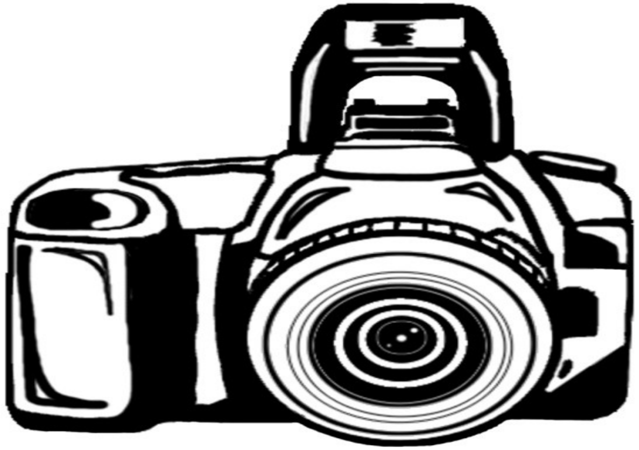
Respiratory symptoms

Skin allergy

Remote Sensing

Basics of Satellite Remote Sensing

Collecting information about an object without being in direct physical contact with it.



- Remote Sensing:
  - The art and science of obtaining information about an object without physically contact between the object and sensor
  - The processes of collecting information about Earth surfaces and phenomena using sensors not in physical contact with the surfaces and phenomena of interest.
  - There is a medium of transmission involved i.e. Earth's Atmosphere.

Applied Sciences Program

Applications to Decision Making: Thematic Areas

Agricultural Efficiency

Air Quality

Climate

Disaster Management

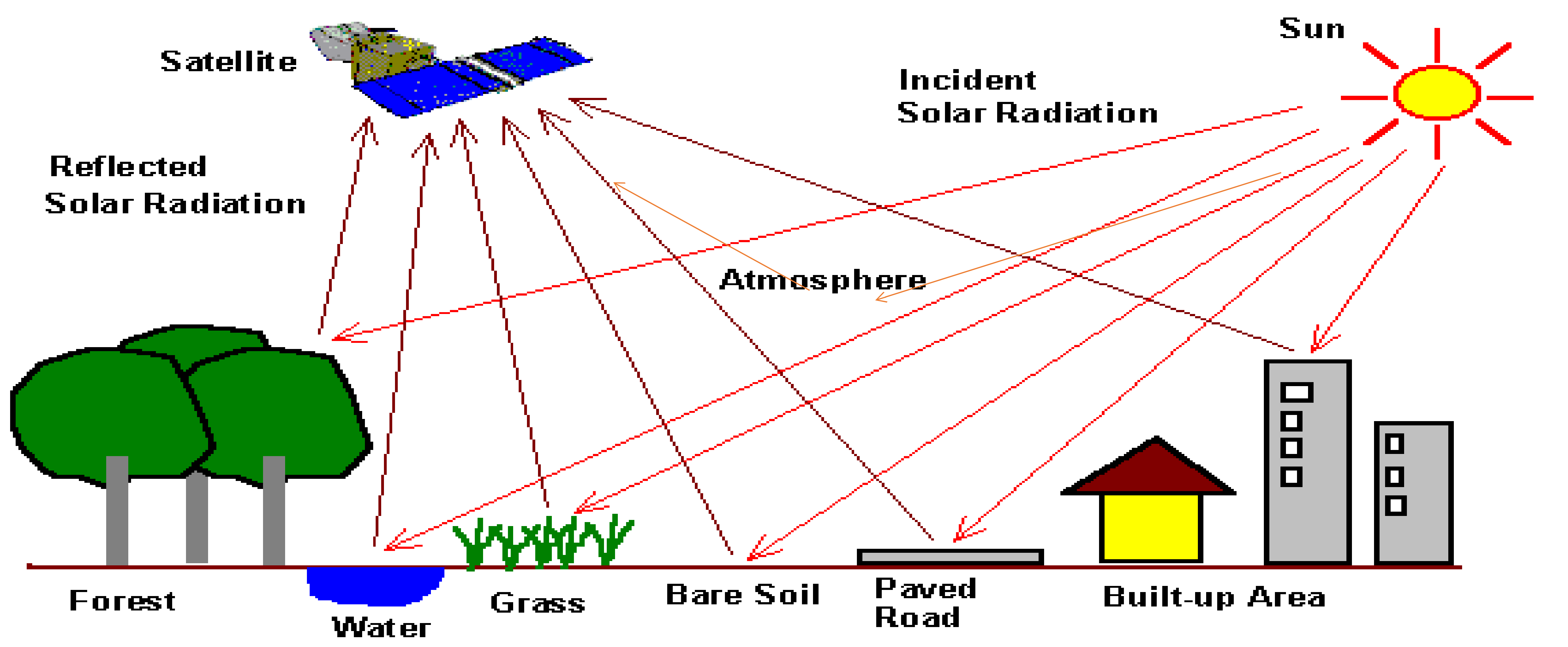
Ecological Forecasting

Public Health

Water Resources

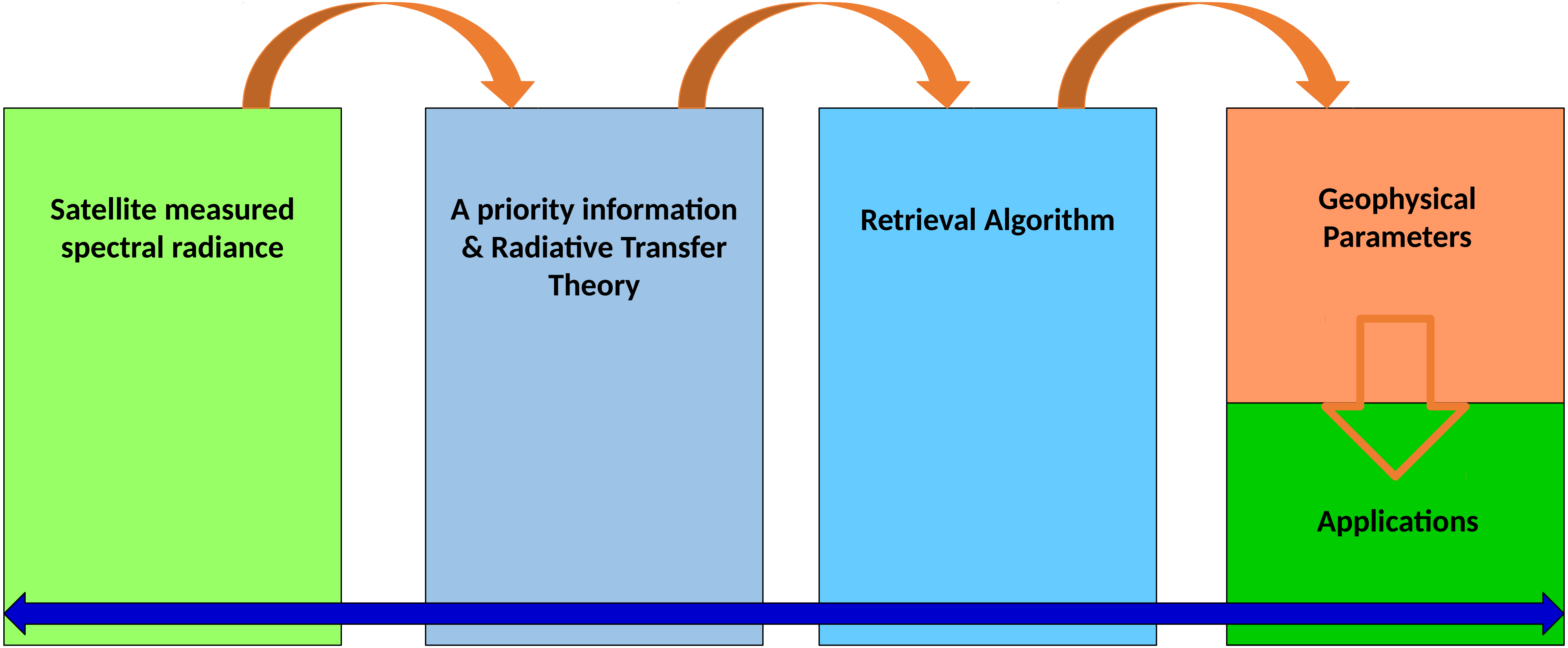
Weather

What does satellite measures ?

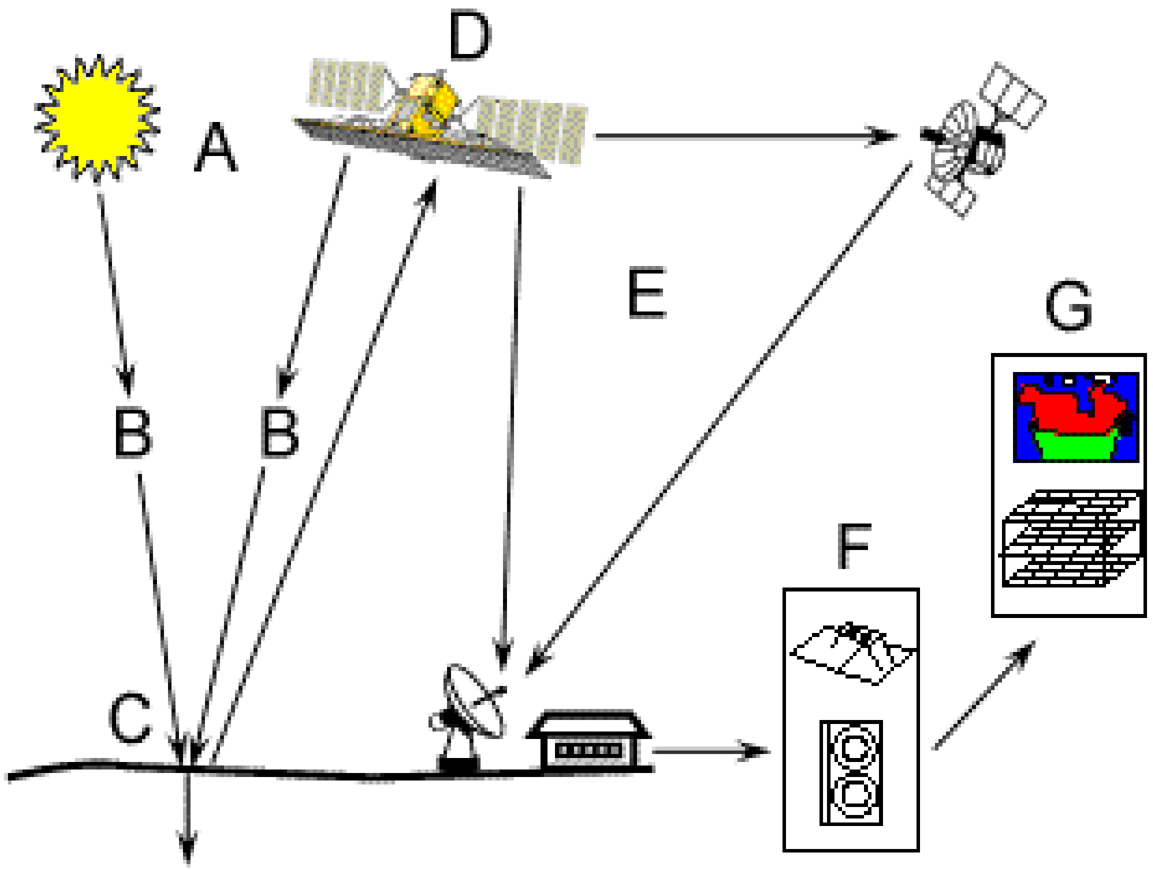


Reference: CCRS/CCT

Remote Sensing Process



Remote Sensing Process Components



Energy Source or Illumination (A)

Radiation and the Atmosphere (B)

Interaction with the Target (C)

Recording of Energy by the Sensor (D)

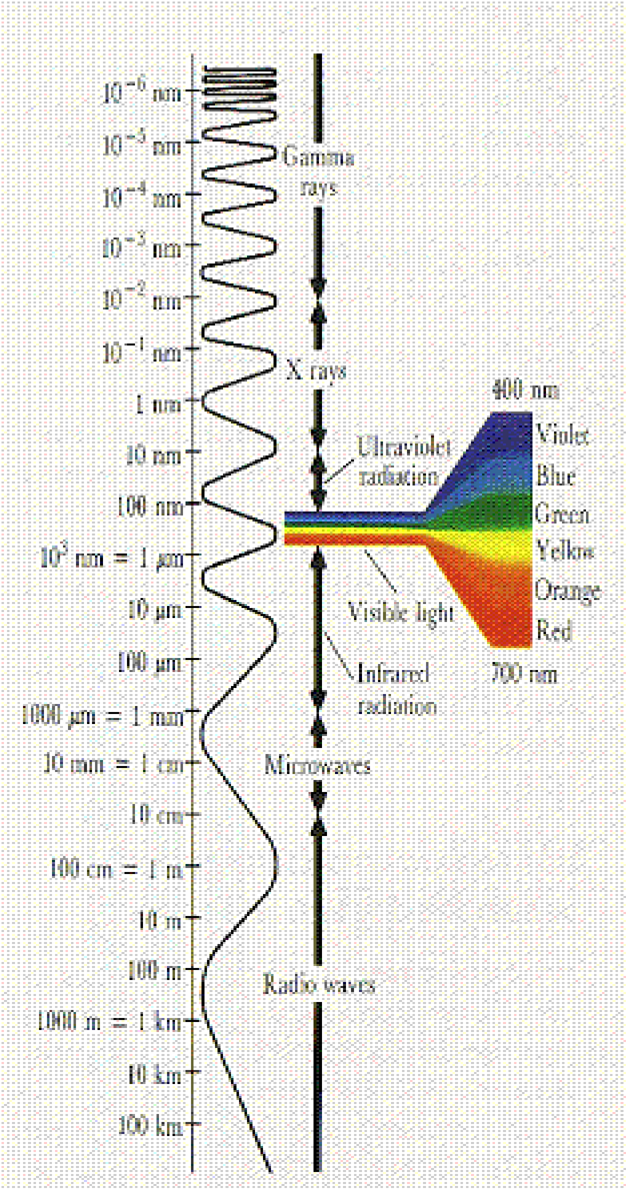
Transmission, Reception, and Processing (E)

Interpretation and Analysis (F)

Application (G)

Wavelength Ranges in Remote Sensing

- **UV:** some absorptions + profile information+ aerosols
- **VIS:** surface information (vegetation)+some absorptions+ aerosol
- **IR:** temperature information + cloud information+ water / ice distinction
- +many absorptions / emissions + profile information
- **MW:** no problems with clouds+ ice / water contrast+ surfaces + some emissions + profile information



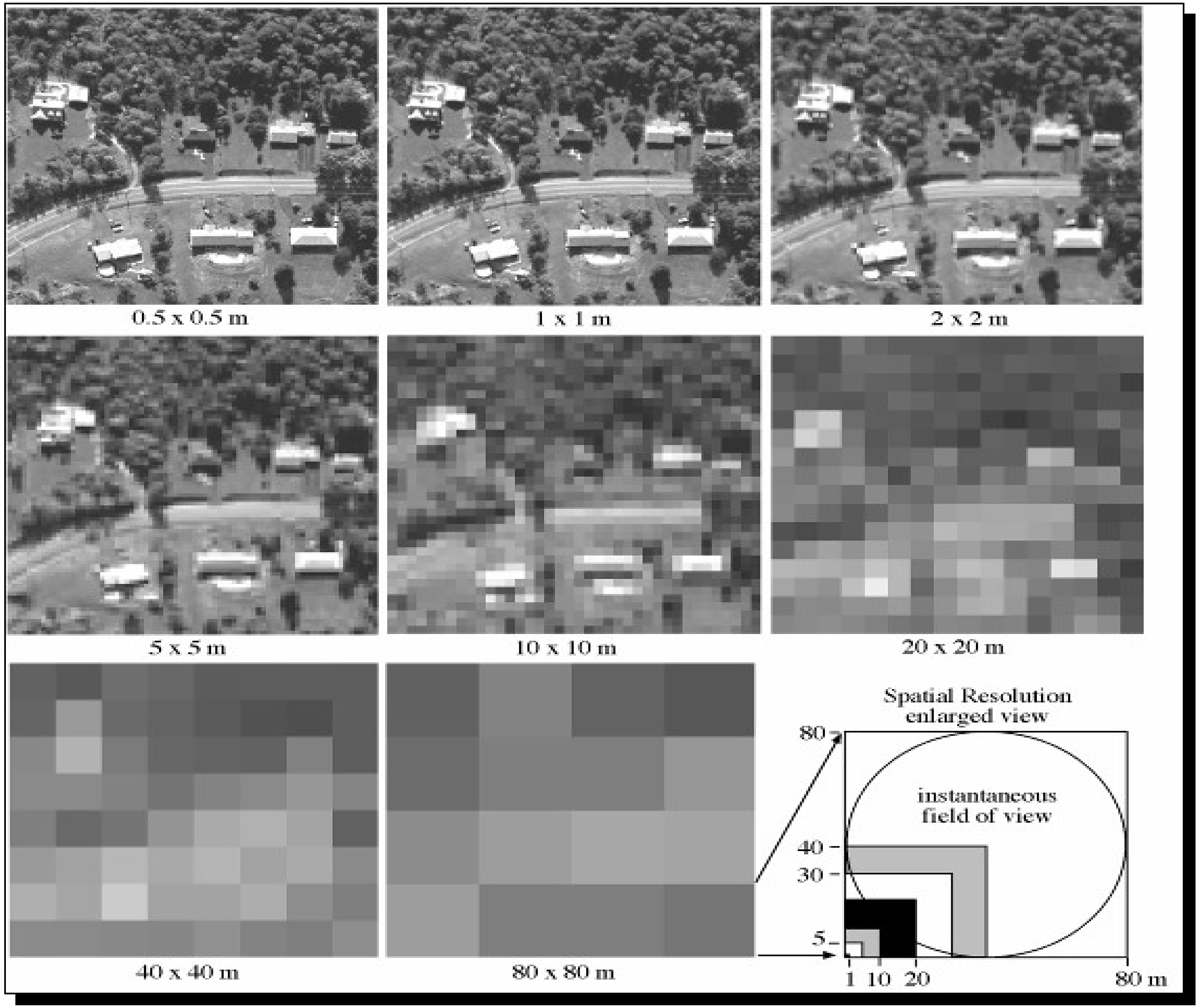
Resolution

- All remote sensing systems have four types of resolution:
  - Spatial
  - Spectral
  - Temporal
  - Radiometric

Fundamental in Remote Sensing: Spatial Resolution

- The earth surface area covered by a pixel of an image is known as spatial resolution

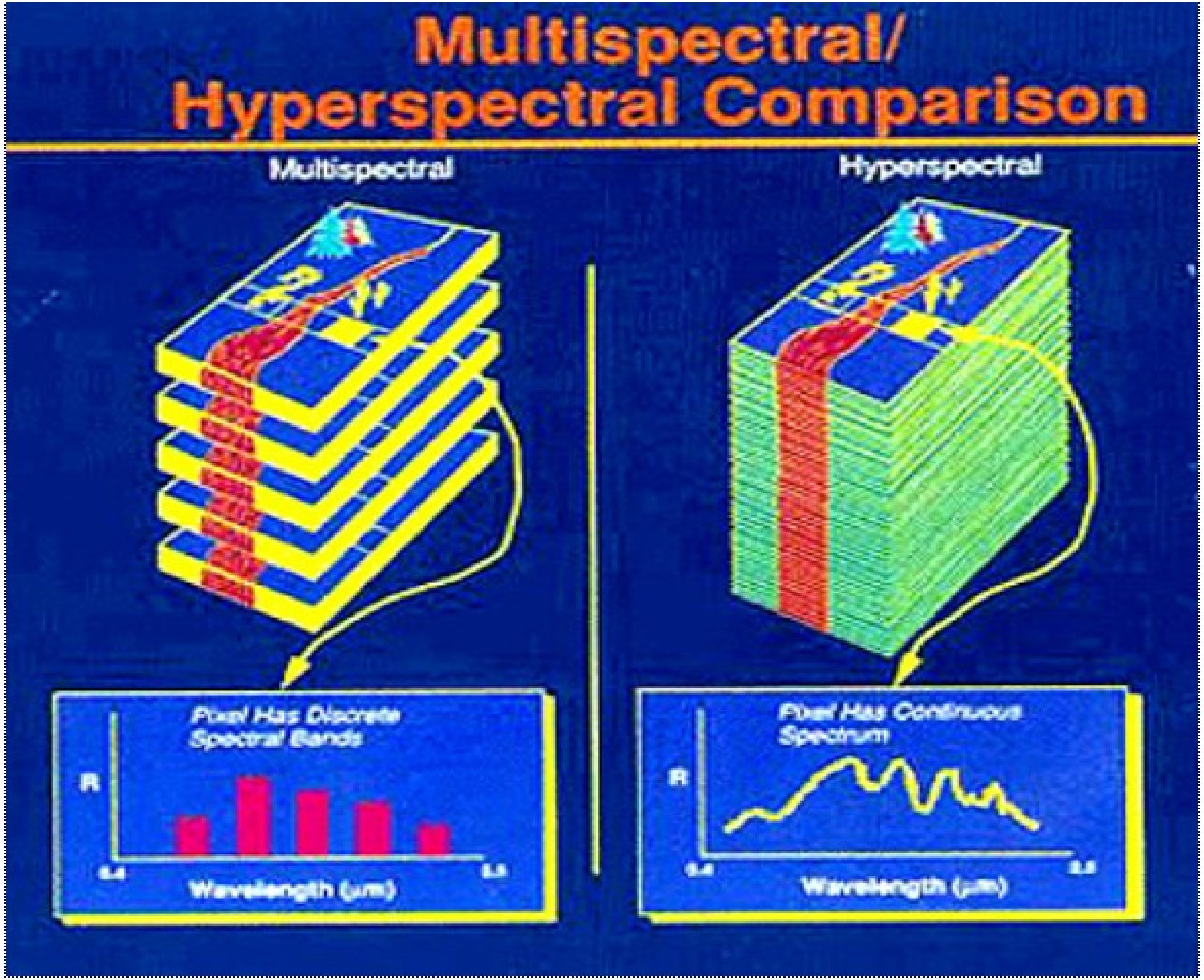
- Large area covered by a pixel means low spatial resolution and vice versa



Fundamental in Remote Sensing: Spectral Resolution

- Is the ability to resolve spectral features and bands into their separate components

- More number of bands in a specified bandwidth means higher spectral resolution and vice versa



Fundamental in Remote Sensing: Temporal Resolution

- Frequency at which images are recorded/ captured in a specific place on the earth.
- The more frequently it is captured, the better or finer the temporal resolution is said to be
- For example, a sensor that captures an image of an agriculture land twice a day has better temporal resolution than a sensor that only captures that same image once a week.

Fundamental in Remote Sensing: Radiometric Resolution

- Sensitivity of the sensor to the magnitude of the received electromagnetic energy determines the radiometric resolution
- Finer the radiometric resolution of a sensor, if it is more sensitive in detecting small differences in reflected or emitted energy

2-bit range

0 → 4

6-bit range

0 → 63

8-bit range

0 → 255

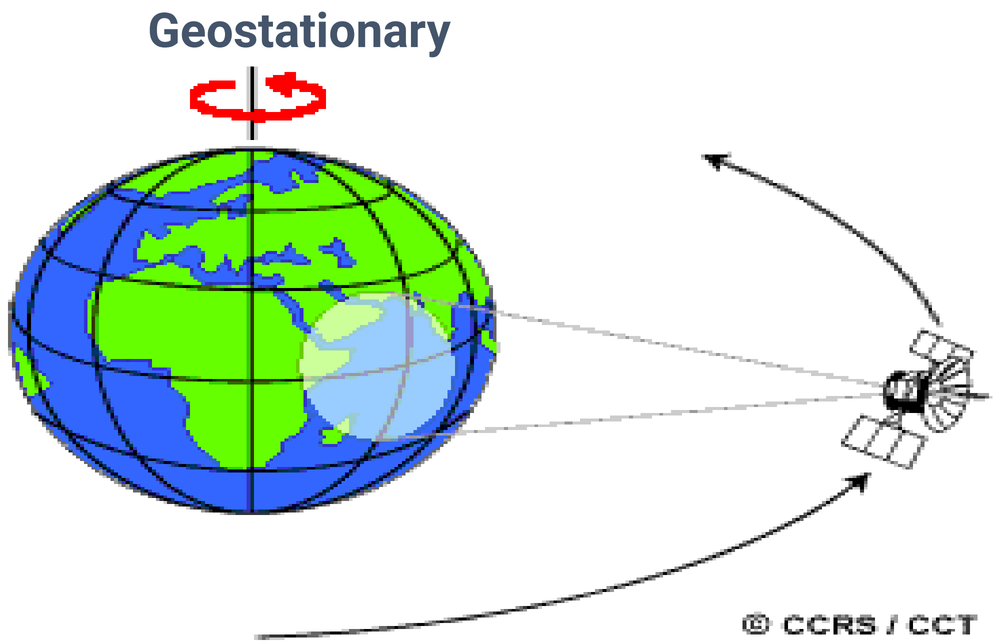
10-bit range

0 →

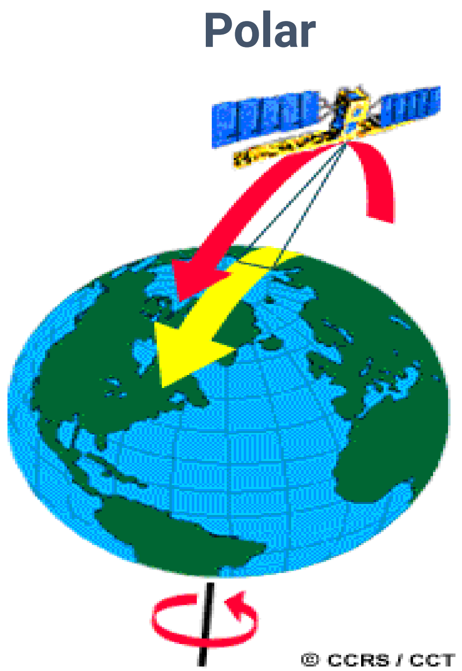
Some of the ways satellites/sensor can be classified

- **Orbits**
  - Polar vs Geostationary
- **Energy source**
  - Passive vs Active …
- **Solar spectrum**
  - Visible, UV, IR, Microwave …
- **Measurement Technique**
  - Scanning, non-scanning, imager, sounders …
- **Resolution (spatial, temporal, spectral, radiometric)**
  - Low vs high (any of the kind)
- **Applications**
  - Weather, Ocean colors, Land mapping, Atmospheric Physics, Atmospheric Chemistry, Air quality, radiation budget, water cycle, coastal management …

Common types of orbits

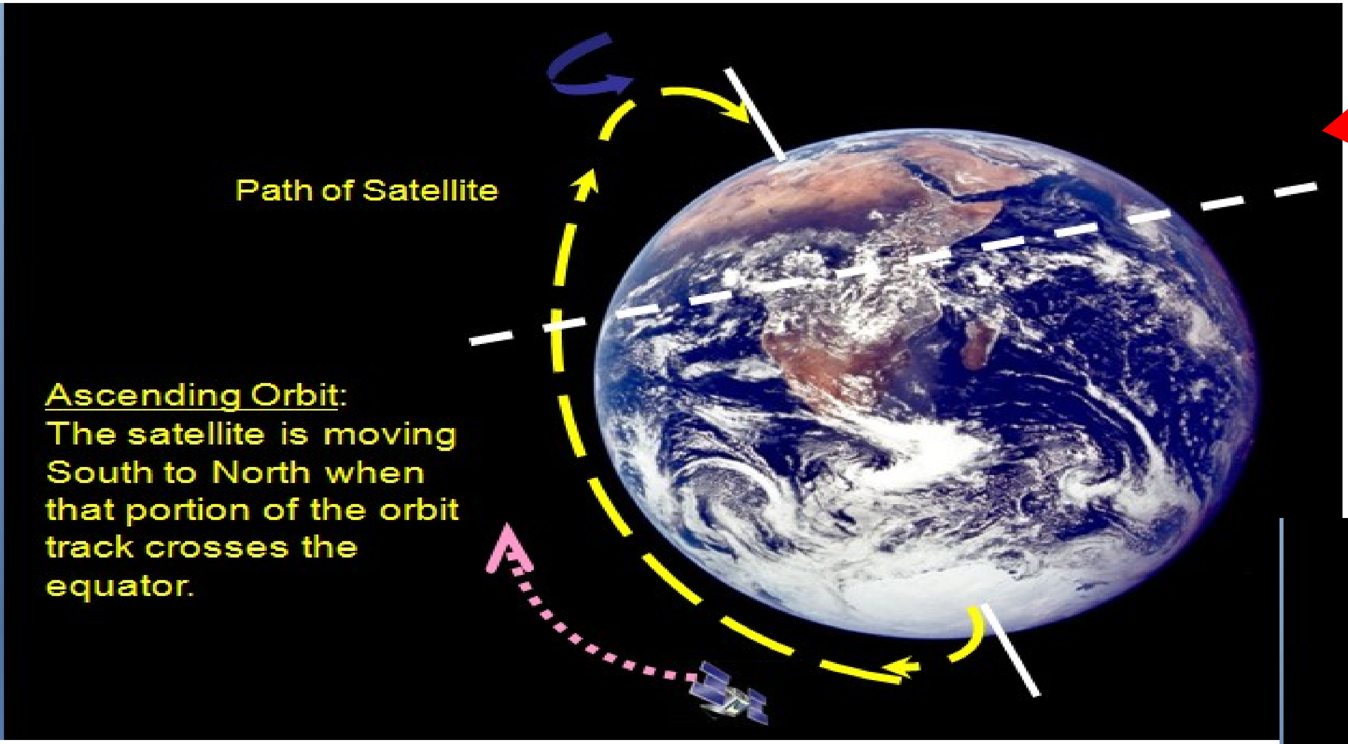


Geostationary orbit
An orbit that has the same Earth's rotational period
Appears 'fixed' above earth
Satellite on equator at ~36,000km

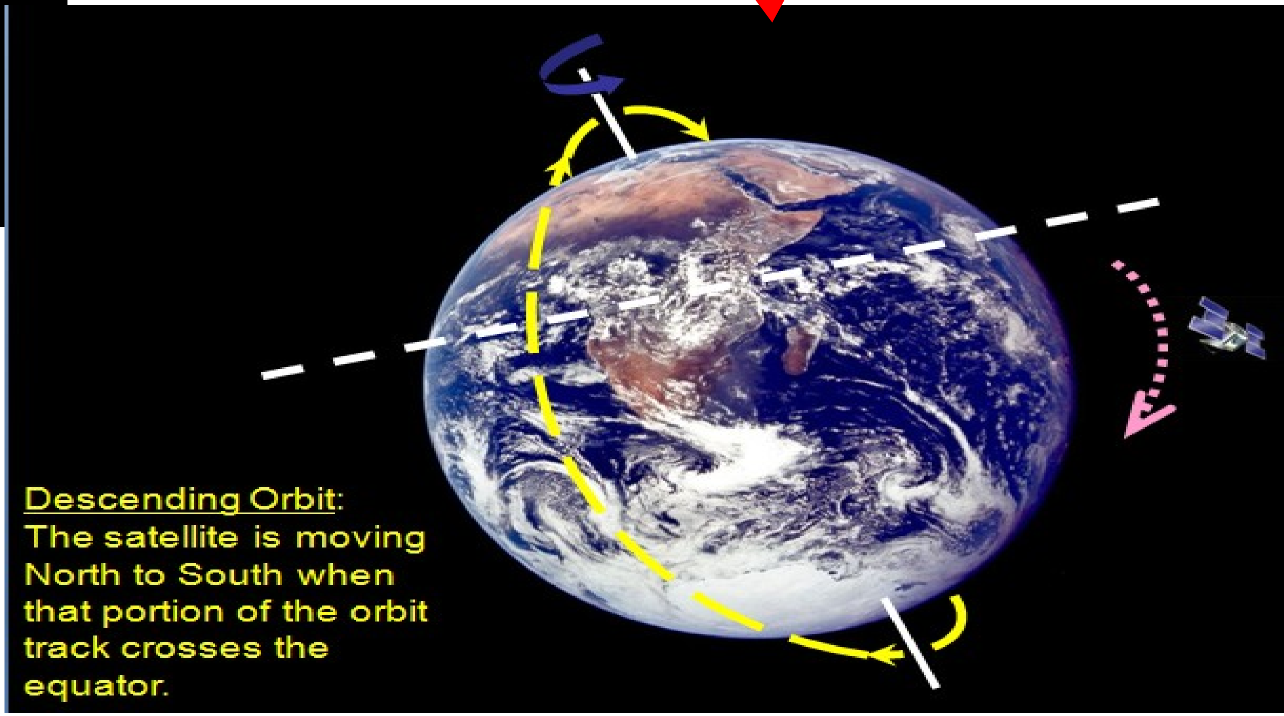


Polar orbiting orbit
fixed circular orbit above the earth, ~600-1000km in sun synchronous orbit with orbital pass at about same **local solar time** each day

Satellite/Sensor Classifications



Ascending vs Descending

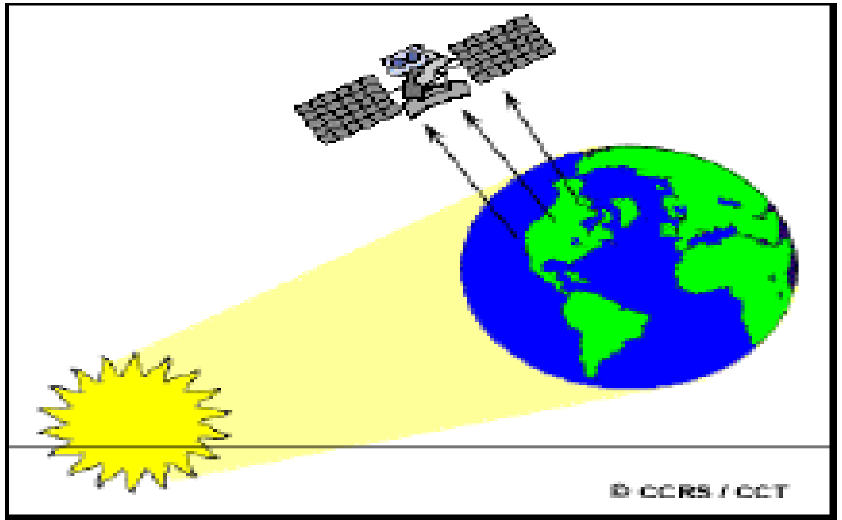


Polar Orbits

Satellite/Sensor Classifications

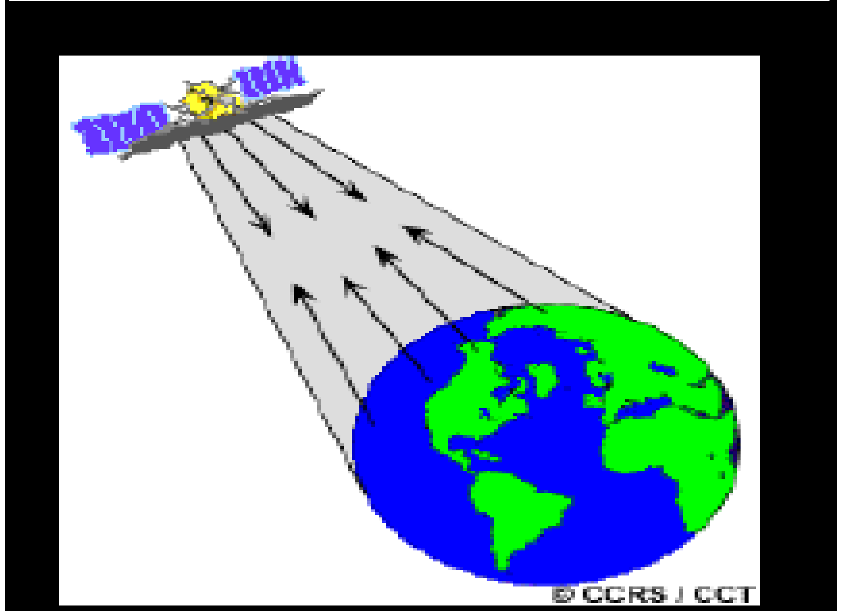
Passive Sensors: Remote sensing systems which measure energy that is naturally available are called passive sensors.

MODIS, MISR, OMI



Active Sensors: The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.

CALIPSO



Remote Sensing Instruments

Ground based instruments

AErosol RObotic NETwork (AERONET)

Satellite based instruments

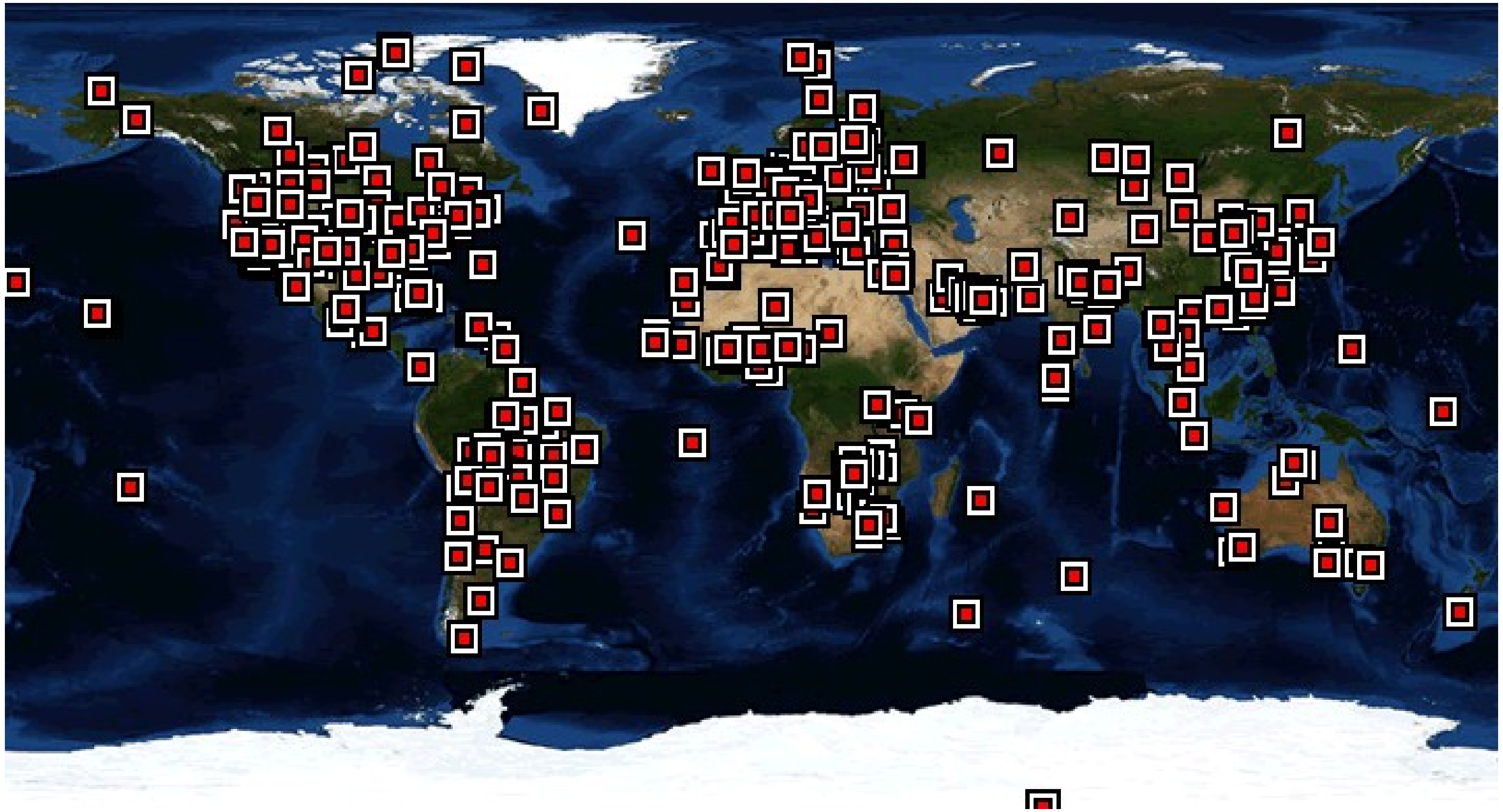
MODerate resolution Imaging Spectroradiometer (MODIS)

Ozone Monitoring Instrument (OMI)

Multiangle Imaging SpectroRadiometer (MISR)

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

AERONET/Sunphotometer



- AErosol RObotic NETwork
- Worldwide collection of sun photometers

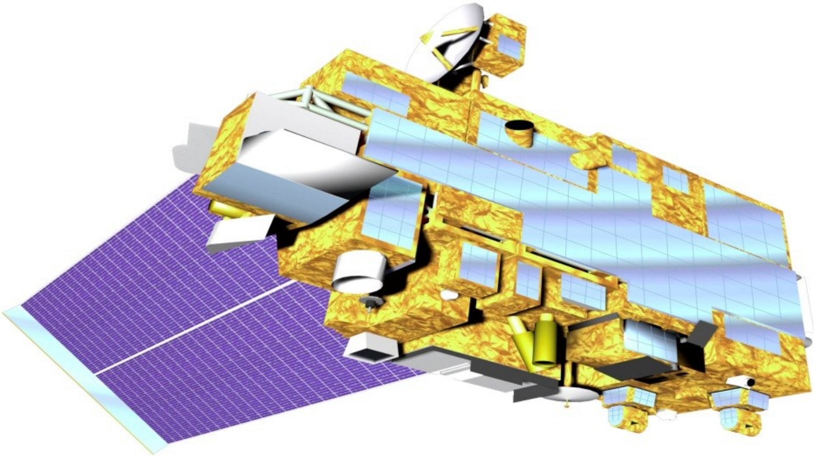
AERONET

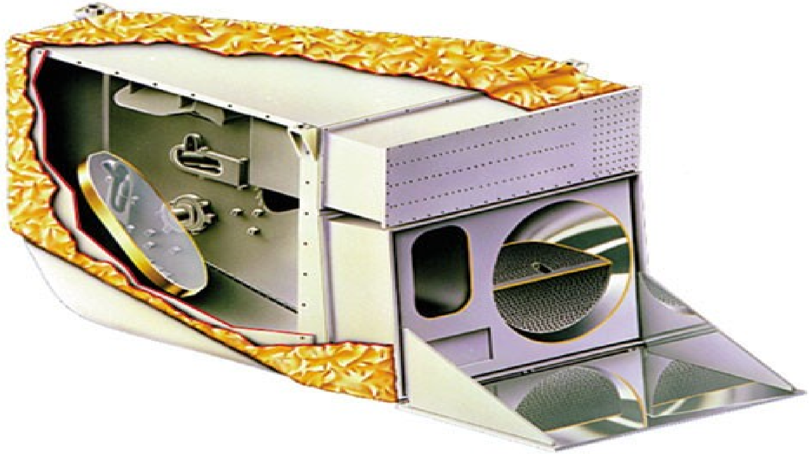
- AERONET provides global observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water.
- The direct sun measurements are made in eight spectral bands requiring approximately 10 seconds at wavelengths of 340, 380, 440, 500, 670, 870, 940 and 1020 nm
- The 940 nm channel is used for column water abundance determination
- Quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (cloud-screened and quality-assured).

MODIS Instrument

❖ Moderate Resolution Imaging Spectroradiometer (MODIS)

- NASA, Terra & Aqua
  - launched 1999, 2002
  - 705 km polar orbits, descending (10:30 a.m.) & ascending (1:30 p.m.)
- Sensor Characteristics
  - 36 spectral bands ranging from 0.41 to 14.385 µm
  - cross-track scan mirror with 2330 km swath width
  - Spatial resolutions:
    - ➢ 250 m (bands 1 - 2)
    - ➢ 500 m (bands 3 - 7)
    - ➢ 1000 m (bands 8 - 36)





Three Separate Algorithms

Land

Ocean

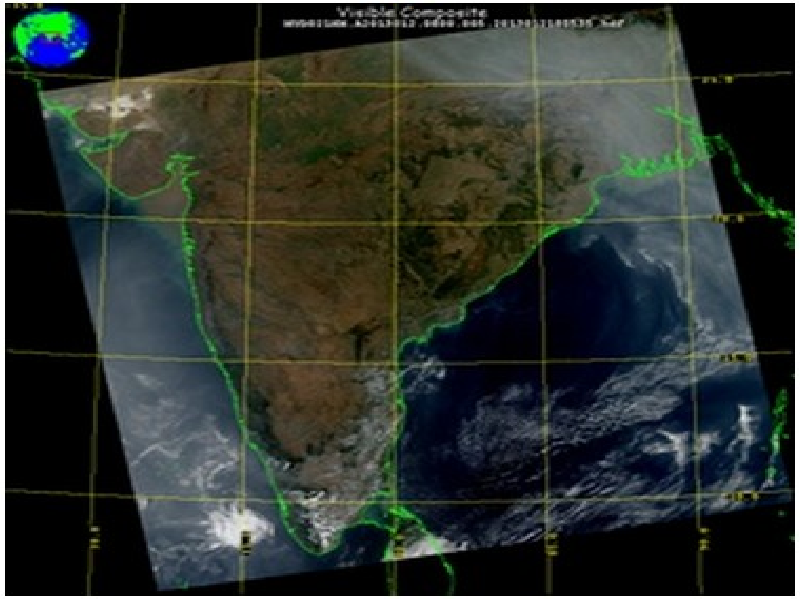
Dark Target
(surface) –
limited to only
over dark vegetate surfaces

Deep Blue –
Used over bright
land surfaces

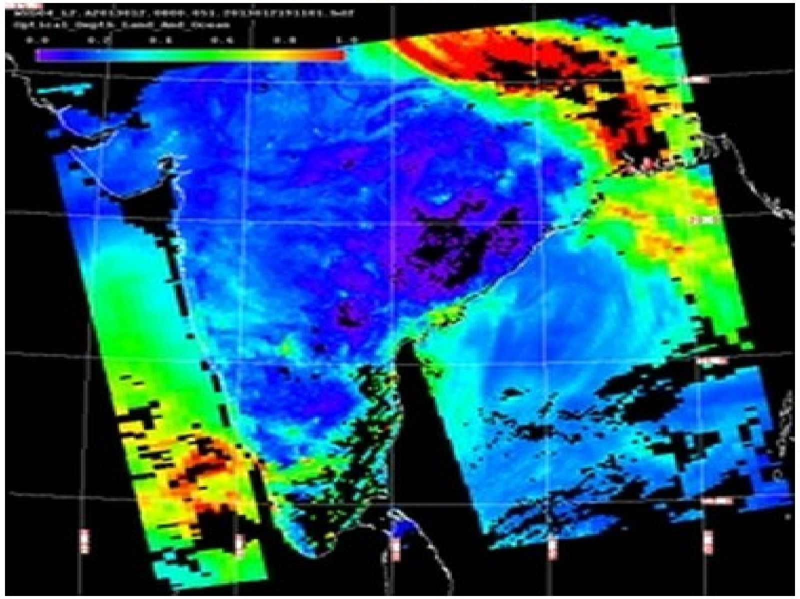
MODIS Levels of Data

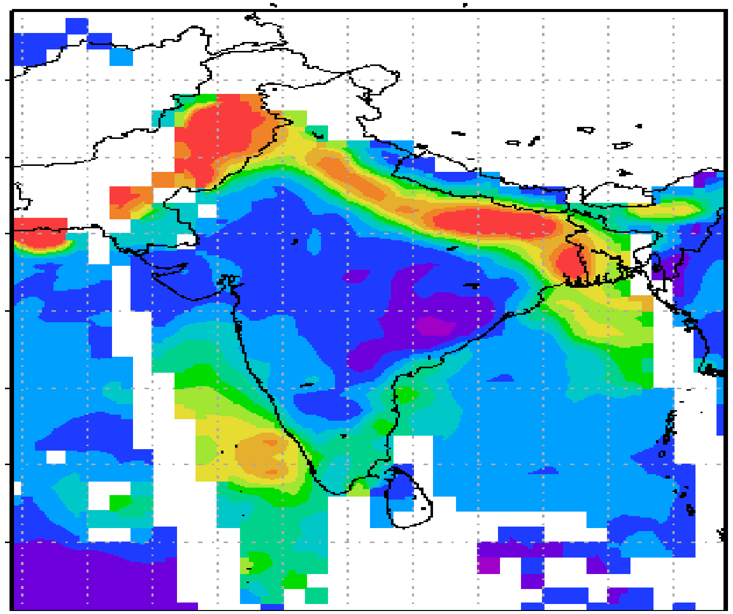
January 12, 2013

RGB



Aerosol Optical Depth





Level 1B

Calibration to Radiance

Level 2

Aerosol Retrieval Algorithm

Level 3

Spatial & Temporal Averaging

Understanding a MODIS File Name

Time Collection

MOD04_L2.A2001079.0255.005.2006289012028.hdf

Product Name

Date - year, Julian day

File processing information

MODIS Aerosol Products

- **MODIS Level 2 data**

  https://lpdaac.usgs.gov/about/news_archive/echo_announces_release_reverb

- **MODIS Level 3 data**

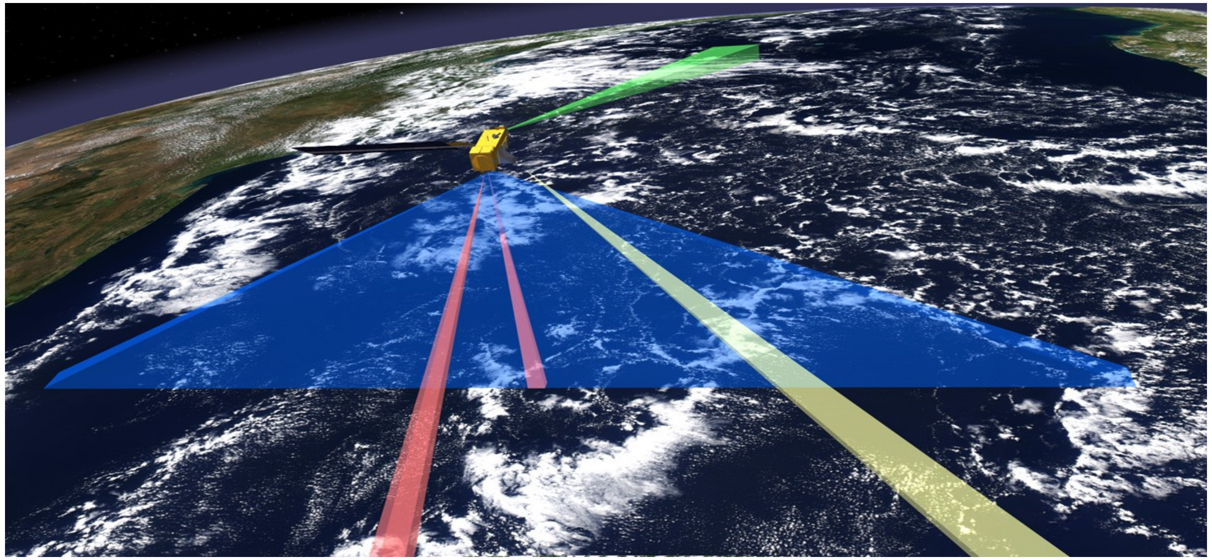
  Giovanni – web tool for imagery visualization and analysis

  https://giovanni.gsfc.nasa.gov/giovanni

- **MODIS Subsets**

  https://earthdata.nasa.gov/earth-observation-data/near-real-time/rapid-response/modis-subsets

Ozone Monitoring Instrument



One of four sensors on the EOS-Aura platform (OMI, MLS, TES, HIRDLS)

An international project: Holland, USA, Finland
Launched on 07-15-04

Instrument Characteristics

-Nadir solar backscatter spectrometer

-Spectral range 270-500 nm (resolution~1nm)

-Spatial resolution: 13X24 km footprint

-Swath width: 2600 km (global daily coverage)

Retrieval Products

Column Amounts
-Ozone (O_3)
-Nitrogen Dioxide (NO_2)
-Sulfur Dioxide: (SO_2)
-Others

Aerosols

OMI data

OMI data site

http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI

Version 003 OMI Level 2, Level 2G, Level-3 and Climatology Products

Short Name & Data Access			Product Description
Level-2 Orbital Swath (Nadir pixels 13x24 km)	Level-2G Global Binned (0.25x0.25 or 0.125x0.125 deg)	Level-3 Global Gridded (0.25x0.25 or 1x1 deg)	
Aerosols			
OMAERUV	OMAERUVG	OMAERUVd	OMI/Aura Near-UV Aerosol Optical Depth and single Scattering Albedo
OMAERO	OMAEROG	OMAEROe	OMI/Aura Multi-Wavelength Aerosol Optical Depth and single Scattering Albedo

OMI-Aura_L2-OMAERUV_2011m1024t0521-o38692_v003-2011m1024t115317.he5

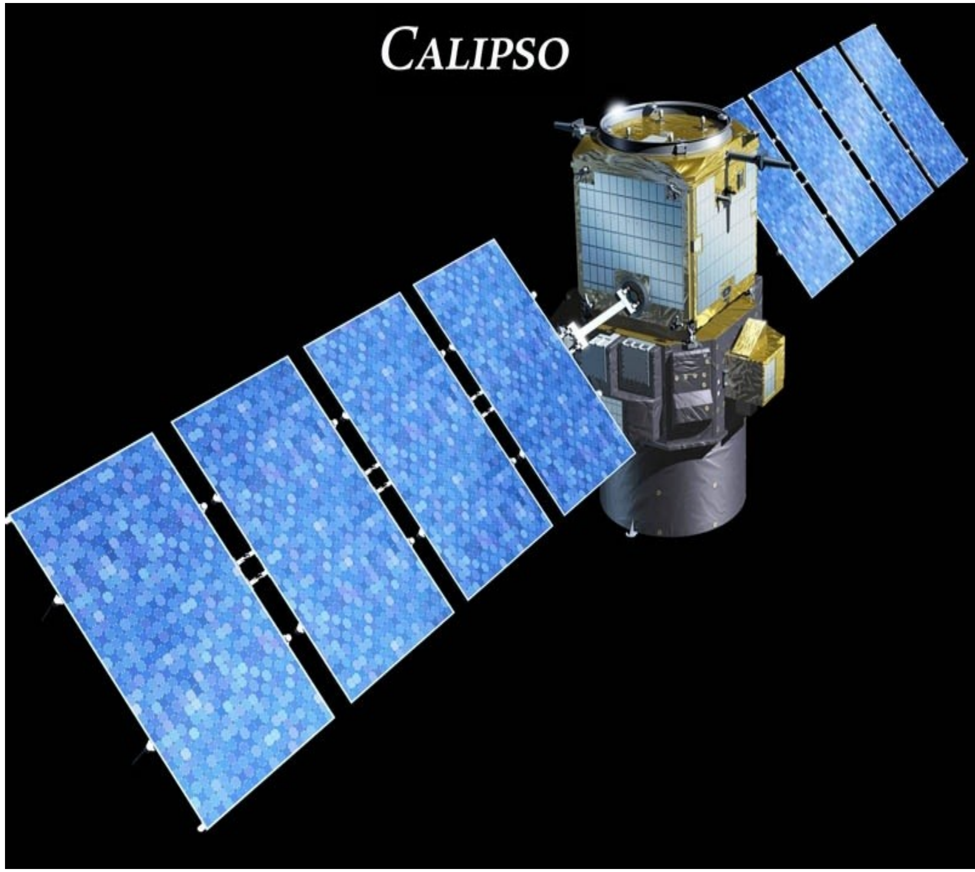
Product name

YYYYmMMDDtHHMM

Cloud-aerosol lidar and infrared pathfinder satellite observations (CALIPSO)

Cloud-aerosol lidar and infrared pathfinder satellite observations (CALIPSO)

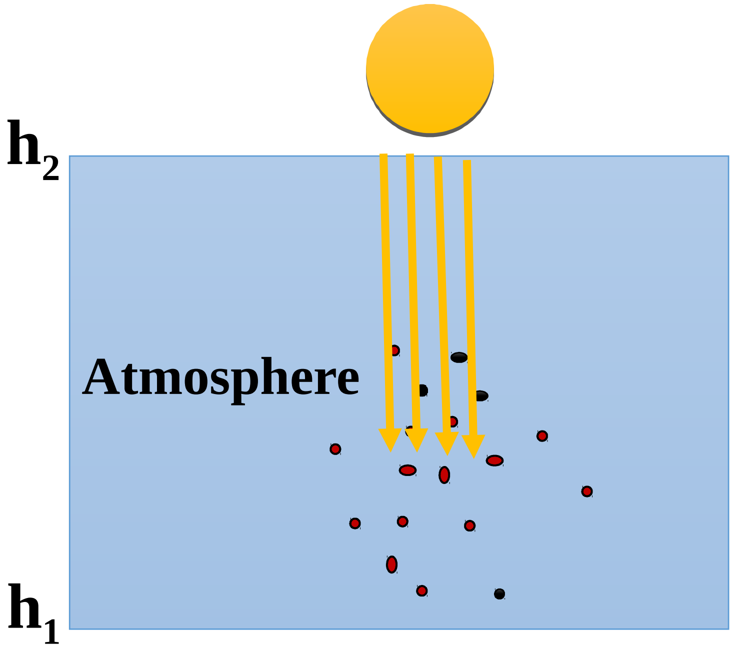
- The CALIPSO satellite was launched on April 28, 2006, with equator crossing times of about 13:30 and 01:30 and a 16-day repeating cycle
- It gives the distribution of aerosols and clouds in vertical atmospheric profiles on the global/regional scale
- It carries a Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument that operates at two wavelengths (532 nm and 1064 nm)
- CALIPSO satellite discriminates the different aerosol types including clean marine, dust, polluted continental, clean continental, polluted dust and smoke



https://www-calipso.larc.nasa.gov/

Aerosol Optical Properties

Aerosol Optical Depth (AOD) and Angstrom Exponent (AE)



$$\mathbf{AOD}(\lambda) = \int_{h_1}^{h_2} \beta_{\mathbf{ext},\lambda}(\mathbf{h})\,dh$$

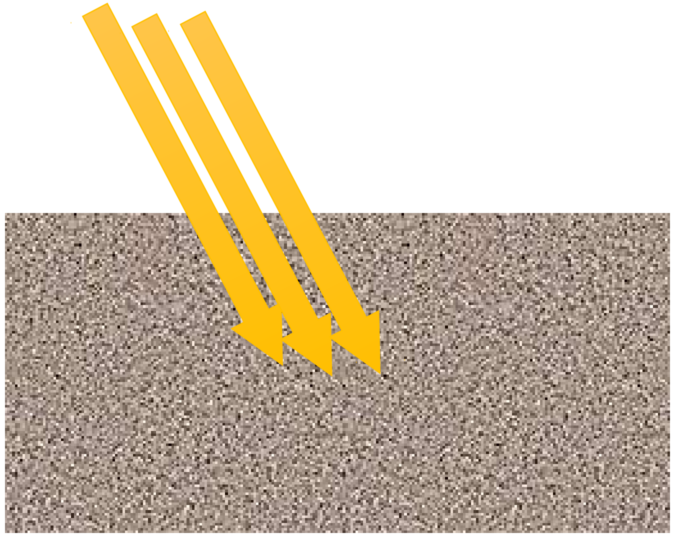
- **AOD** represents the total extinction of solar radiation caused by aerosol via **scattering** or **absorption**

- **AE** measures the aerosol size distribution

$$AE = -d\ln[AOD(\lambda)]/d\ln(\lambda)$$

- AE is the size indicator of aerosol particle

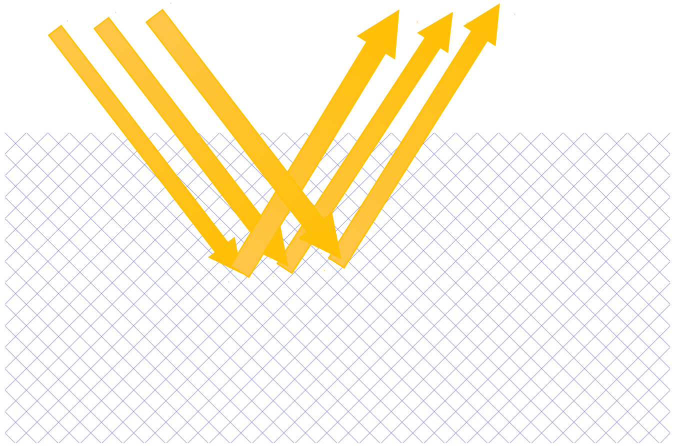
Aerosol Index (AI)



AI is the ratio of measured to calculated radiances (at 360 nm)

$$AI = 100\log_{10}(I_{360}measured/I_{360}calculated)$$

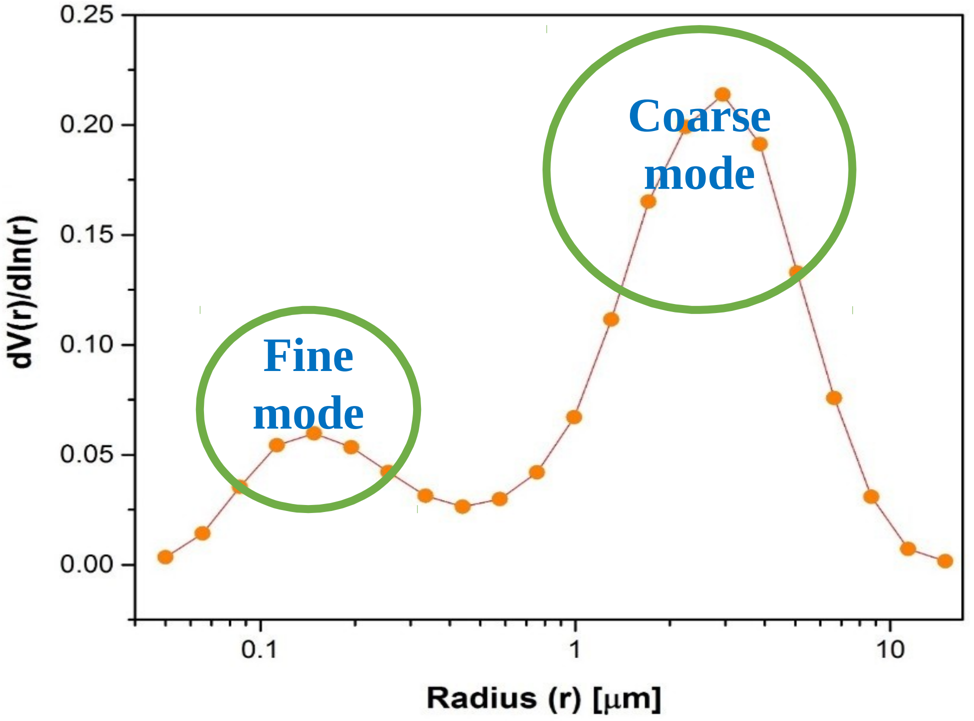
- **AI** separates the absorbing from non-absorbing aerosols in UV region



- AI > 0 for totally absorbing particles
- AI < 0 for purely scattering particles

Aerosol Optical Properties

Fine Mode Fraction (FMF) and Coarse Mode Fraction (CMF)



FMF/CMF of AOD is the fraction of fine/coarse mode AOD to the total AOD

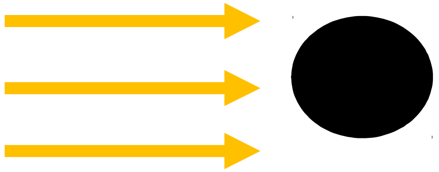
$$\mathbf{FMF} = \frac{\mathbf{AOD_{fine\ mode}}}{\mathbf{AOD_{total}}}$$

$$\mathbf{CMF} = \frac{\mathbf{AOD_{coarse\ mode}}}{\mathbf{AOD_{total}}}$$

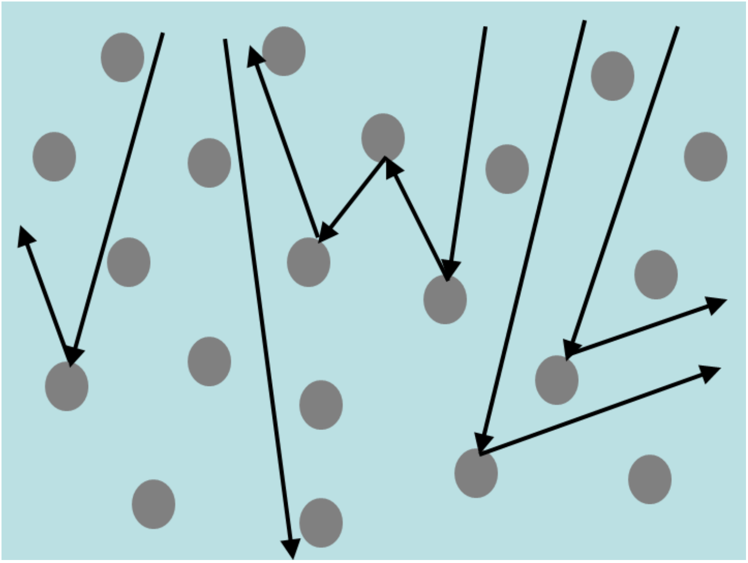
- **FMF** gives information about the size distribution
  - FMF = 0 for single coarse mode particle
  - FMF = 1 for single fine mode particle

- Fine mode aerosols: 0.1 to 0.25μm
- Coarse mode aerosols: 1.0-2.5μm

Single Scattering Albedo (SSA)



Absorption



Scattering

SSA is the ratio of scattering efficiency ($Qscat$) to total extinction efficiency ($Qext$):

SSA is the ratio of scattering efficiency to total extinction efficiency:

$$SSA = \frac{Qscat}{Qext} = \frac{Qscat}{Qscat + Qabs}$$

- **SSA** is used to distinguish absorbing from non-absorbing aerosols
  - SSA= 0 for totally absorbing (dark) particles
  - SSA = 1 for purely scattering particles

Atmospheric Forcing

- In order to understand how the Earth's climate is changing, it is critical to make sense of each mechanism that causes warming or cooling in the atmosphere
- Each process that changes the balance of radiation coming into and going out of the Earth-Atmosphere system is known as atmospheric forcing
- The long wave (LW) and shortwave (SW) radiative forcing at the surface are important components of the Earth's radiation balance

Radiative Transfer Equations

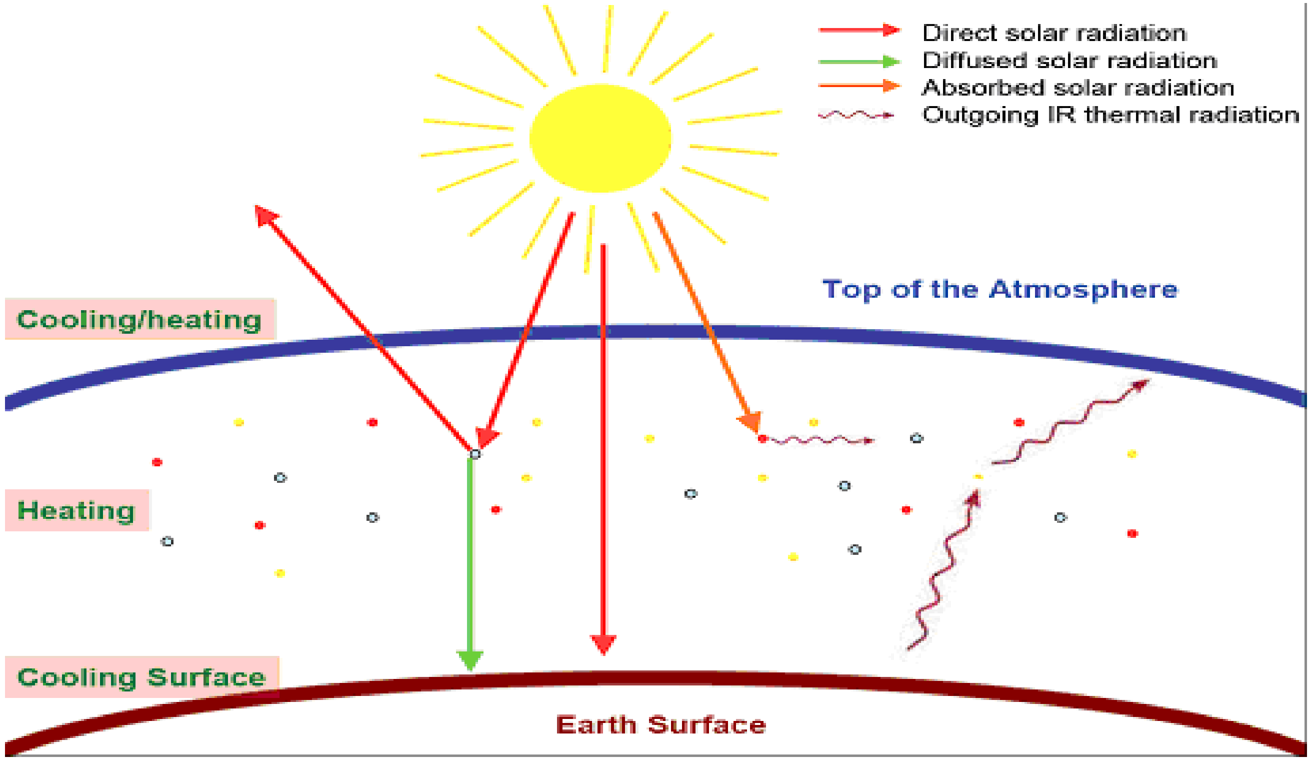
- Once the solutions for the hemispheric intensities are known, it is easy to calculate hemispheric fluxes by performing the angular integrations
- Assumes that there is no dependency on φ in a plane-parallel atmosphere

Upward Fluxes

$$F_\lambda^{\uparrow} = 2\pi \int_0^1 I_\lambda^{\uparrow}(\mu)\mu d\mu$$

Downward Fluxes

$$F_\lambda^{\downarrow} = 2\pi \int_0^1 I_\lambda^{\downarrow}(-\mu)\mu d\mu$$



The **total net flux** can be defined as:

$$F_{net} = F^{\uparrow} - F^{\downarrow}$$

$F_{net} < 0$ ⇒ cooling the atmosphere

$F_{net} > 0$ ⇒ heating the atmosphere

$$\text{Heating rate} = \frac{\partial T}{\partial t} = \frac{g}{C_p}\frac{F_{net}}{\Delta P}$$

Aerosol Radiative Forcing (ARF)

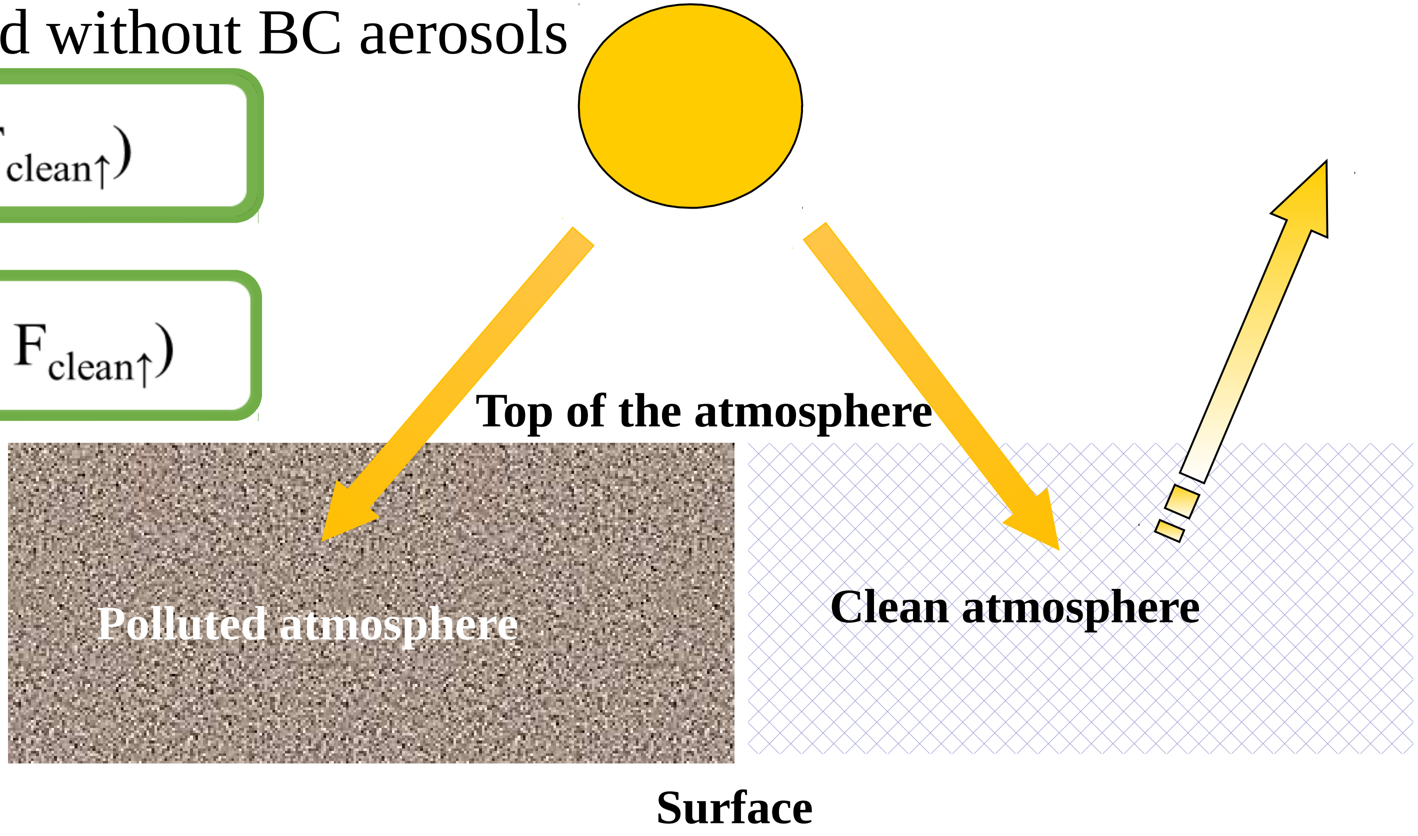
- The Aerosol radiative forcing at the TOA and the surface is obtained as the difference between the down and up fluxes for both with and without BC aerosols

$$F_{TOA} = (F_{aerosol\downarrow} - F_{aerosol\uparrow}) - (F_{clean\downarrow} - F_{clean\uparrow})$$

$$F_{Surface} = (F_{aerosol\downarrow} - F_{aerosol\uparrow}) - (F_{clean\downarrow} - F_{clean\uparrow})$$

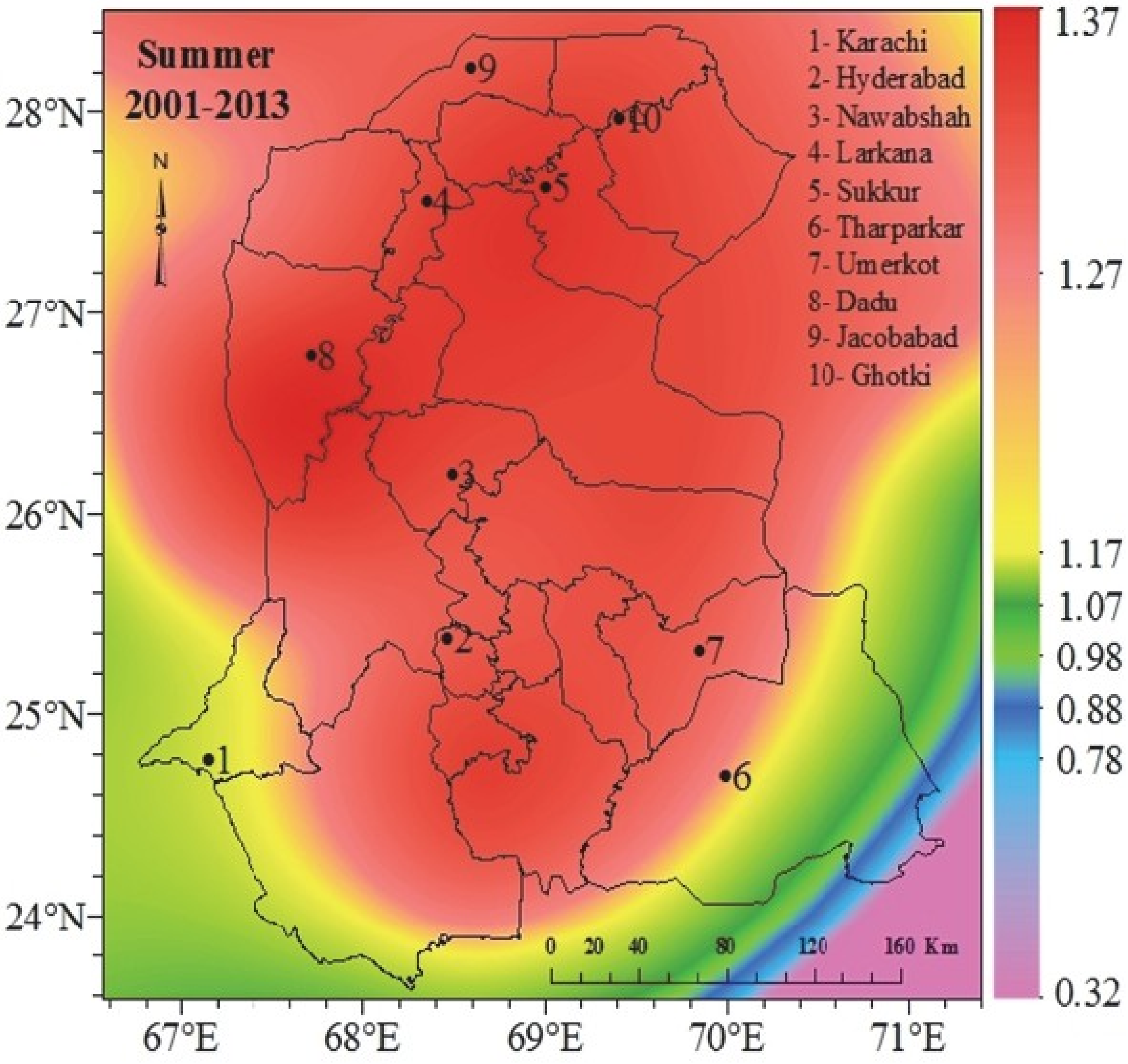
$$\Delta F_{Atmosphere} = F_{TOA} - F_{Surface}$$

$$\text{Heating Rate} = \frac{g}{C_p}\frac{\Delta F_{Atmosphere}}{\Delta P}$$



Analysis of Aerosol Optical Properties

MODIS Aerosol Optical Depth Product



Sharif et al., (2015)

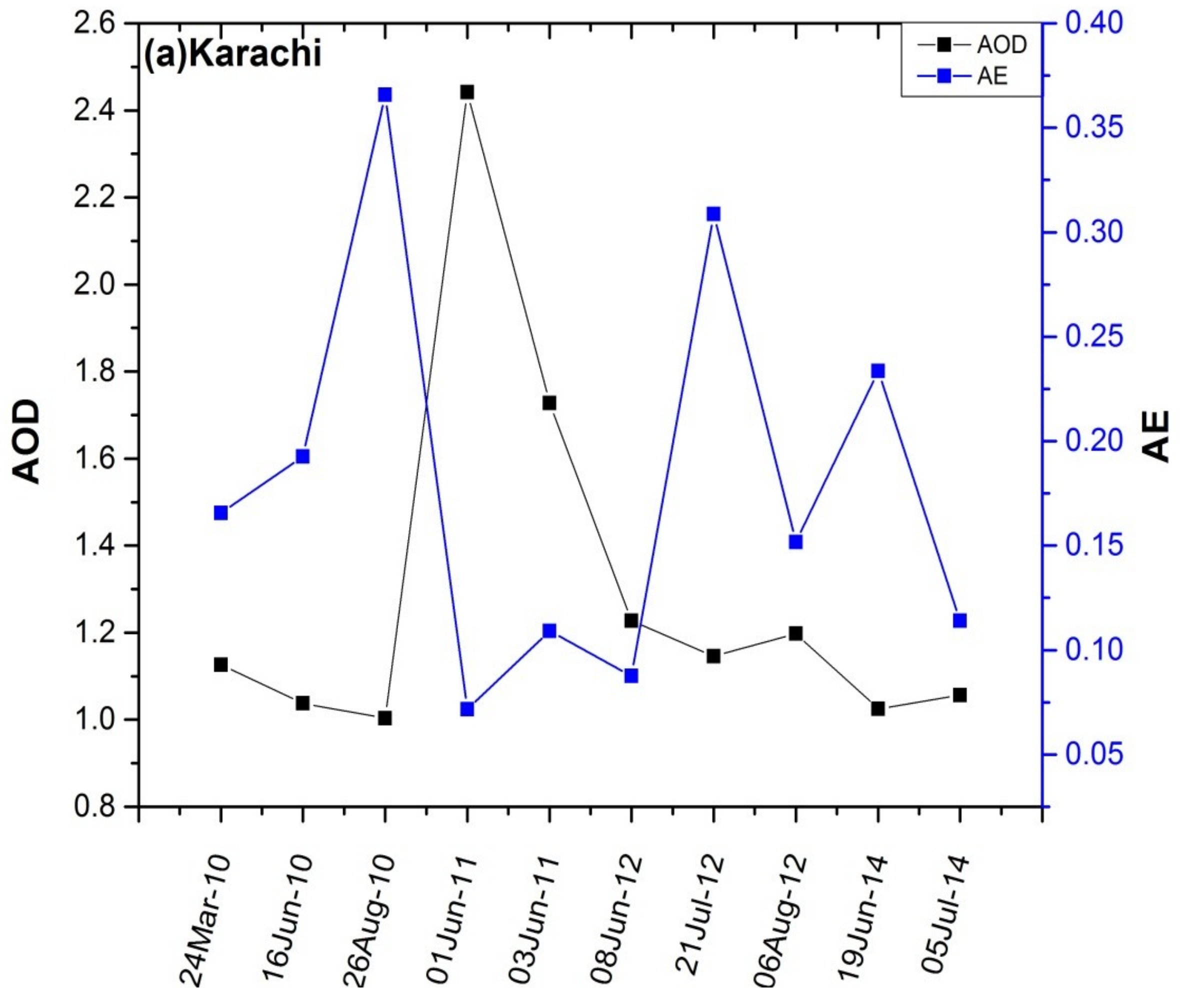
MOD04 or MYD04

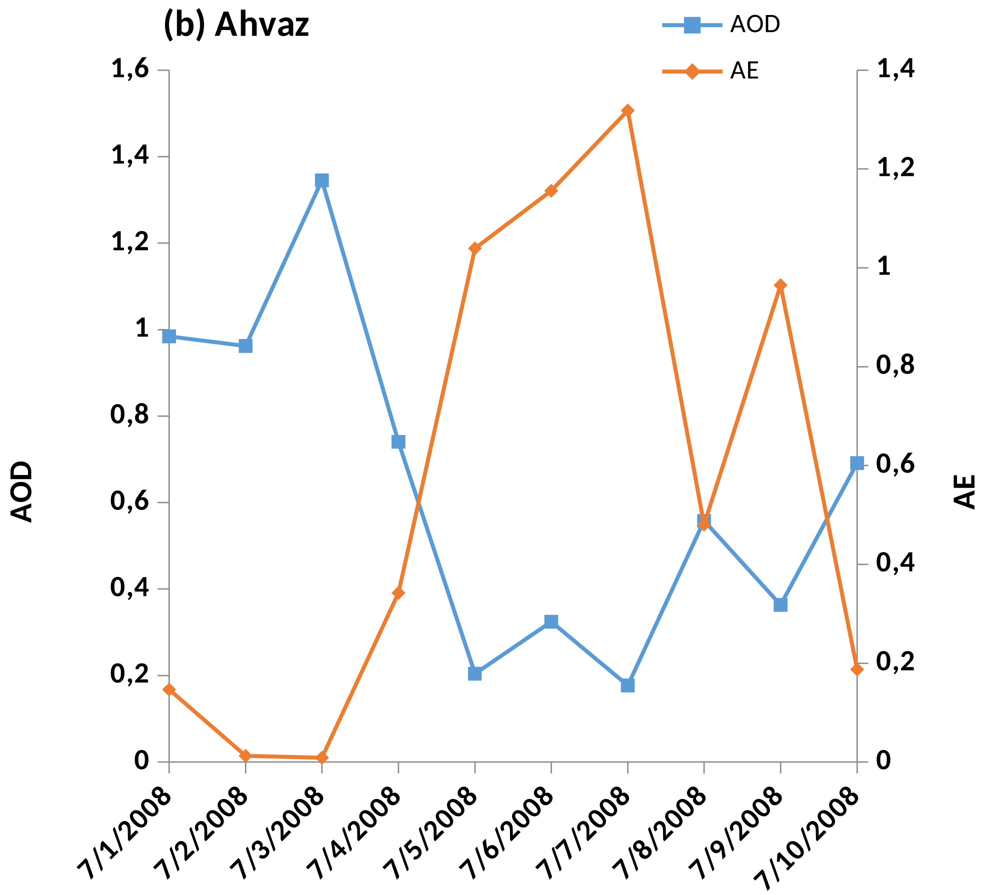
10 km – instantaneous
01 deg – daily, weekly, monthly

- At least two daytime overpasses - Terra and Aqua
- Sensitive to Boundary Layer
  Industrial, smoke & dust aerosols
- Well validated over land

Aerosol Optical Properties

Aerosol Optical Depth (AOD) and Angstrom Exponent (AE) on Dusty Days

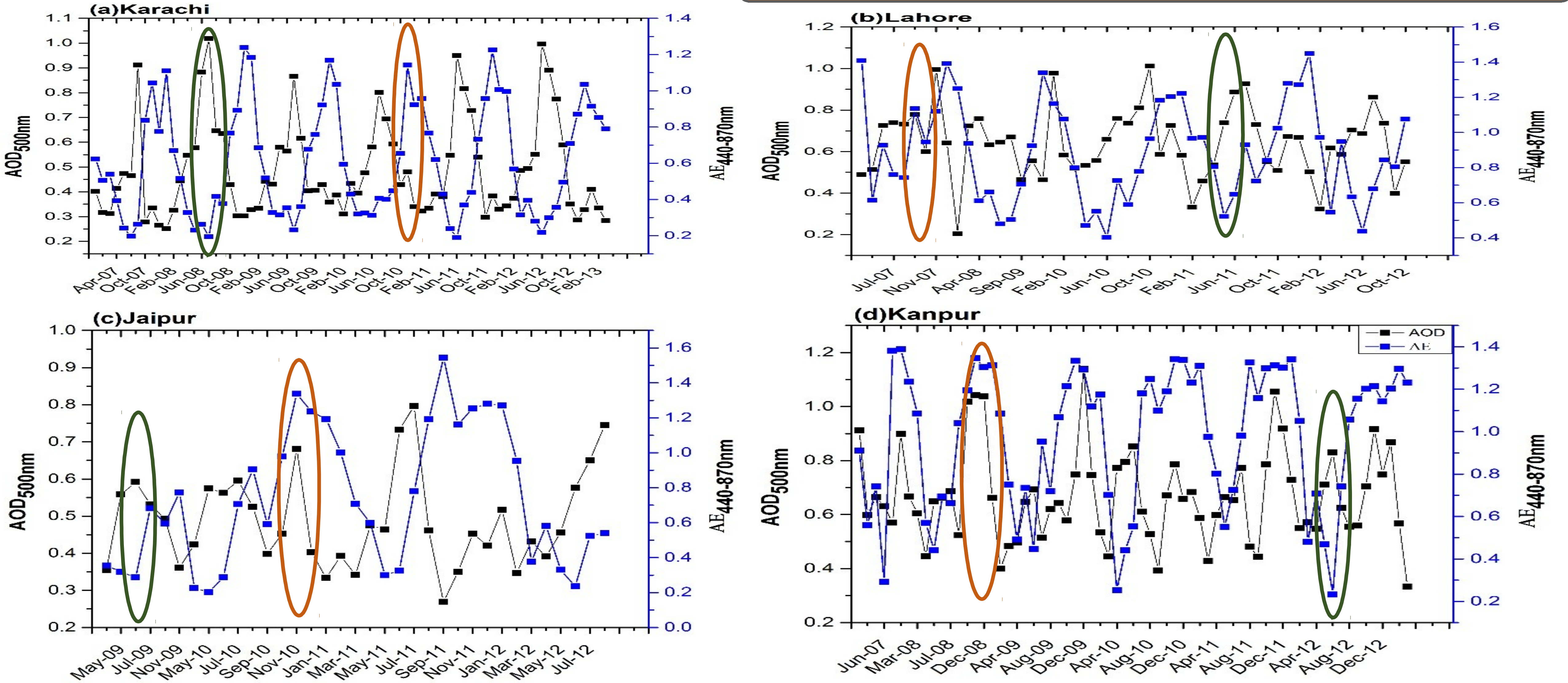




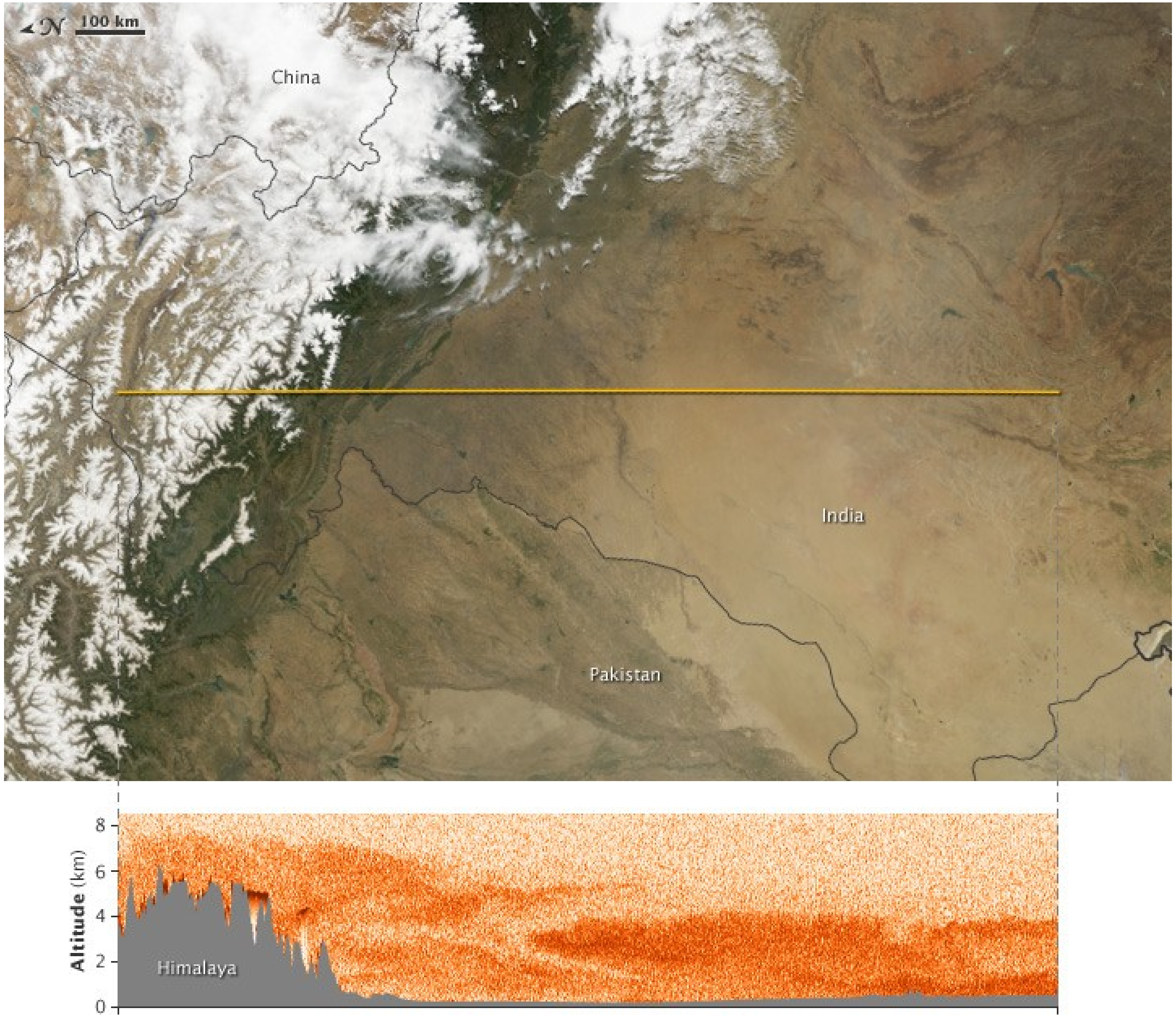
Monthly Averaged Variability of AOD and AE

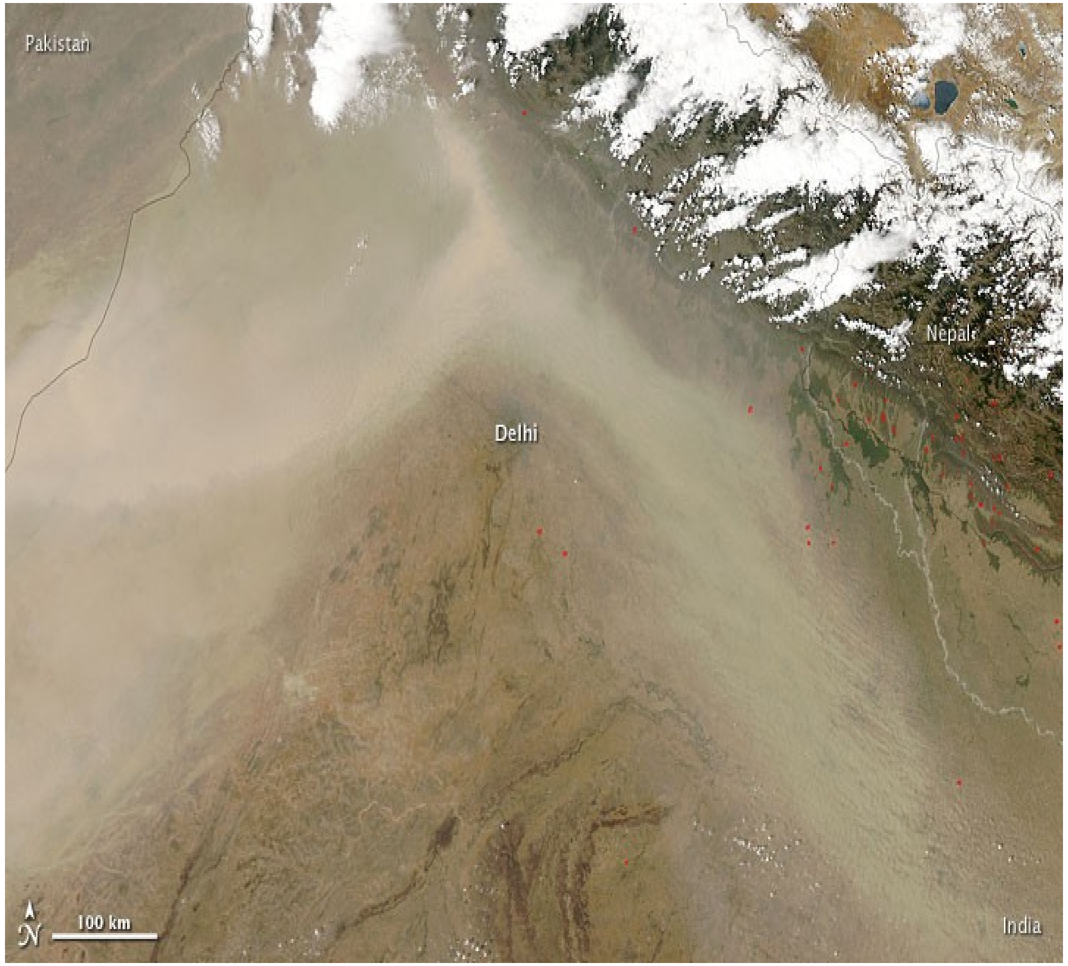
High AOD with low AE during summer and pre-monsoon months

High AOD with high AE during winter and post-monsoon

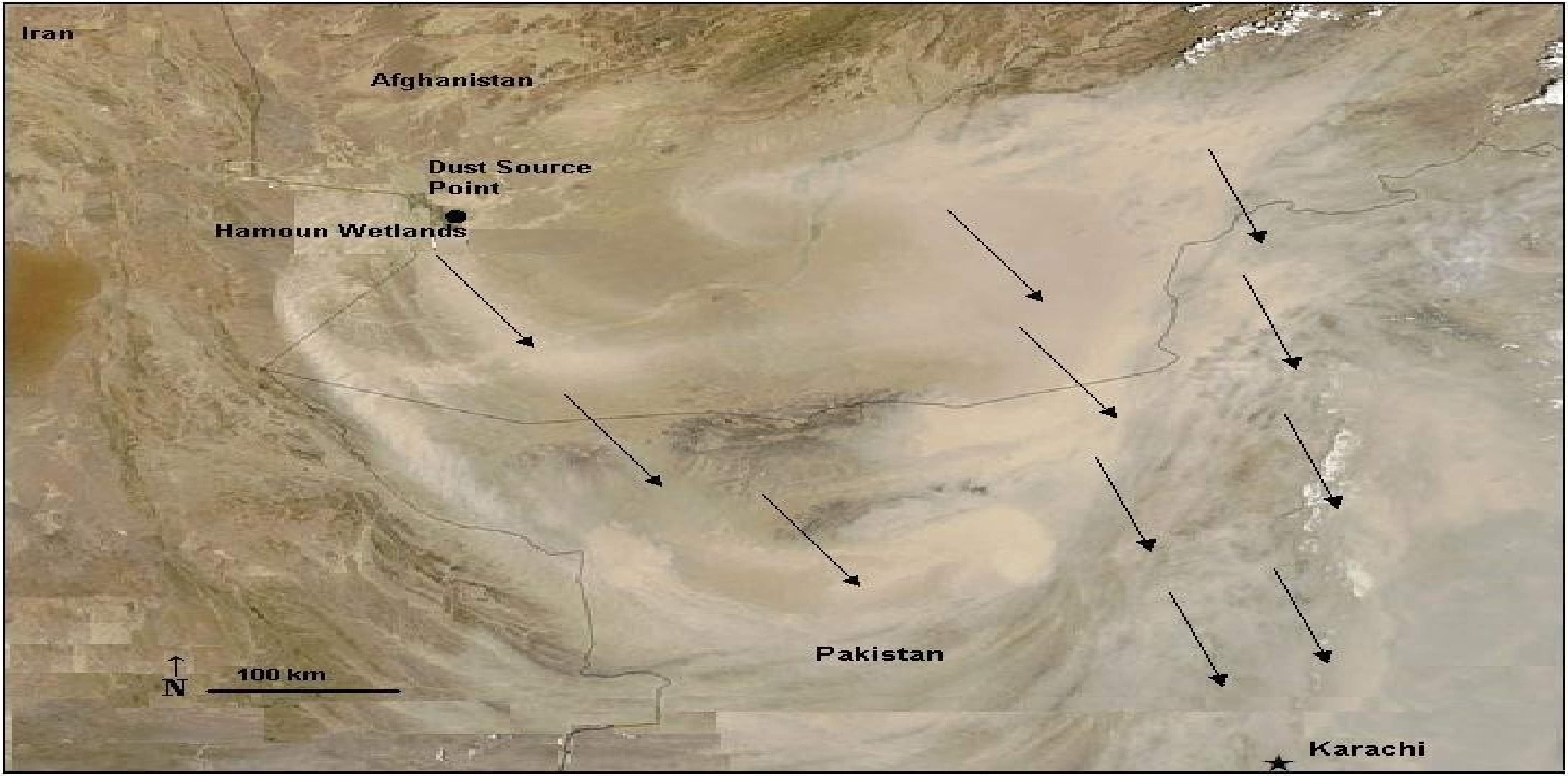


Evidence of Dust by MODIS in the Himalayan foothills

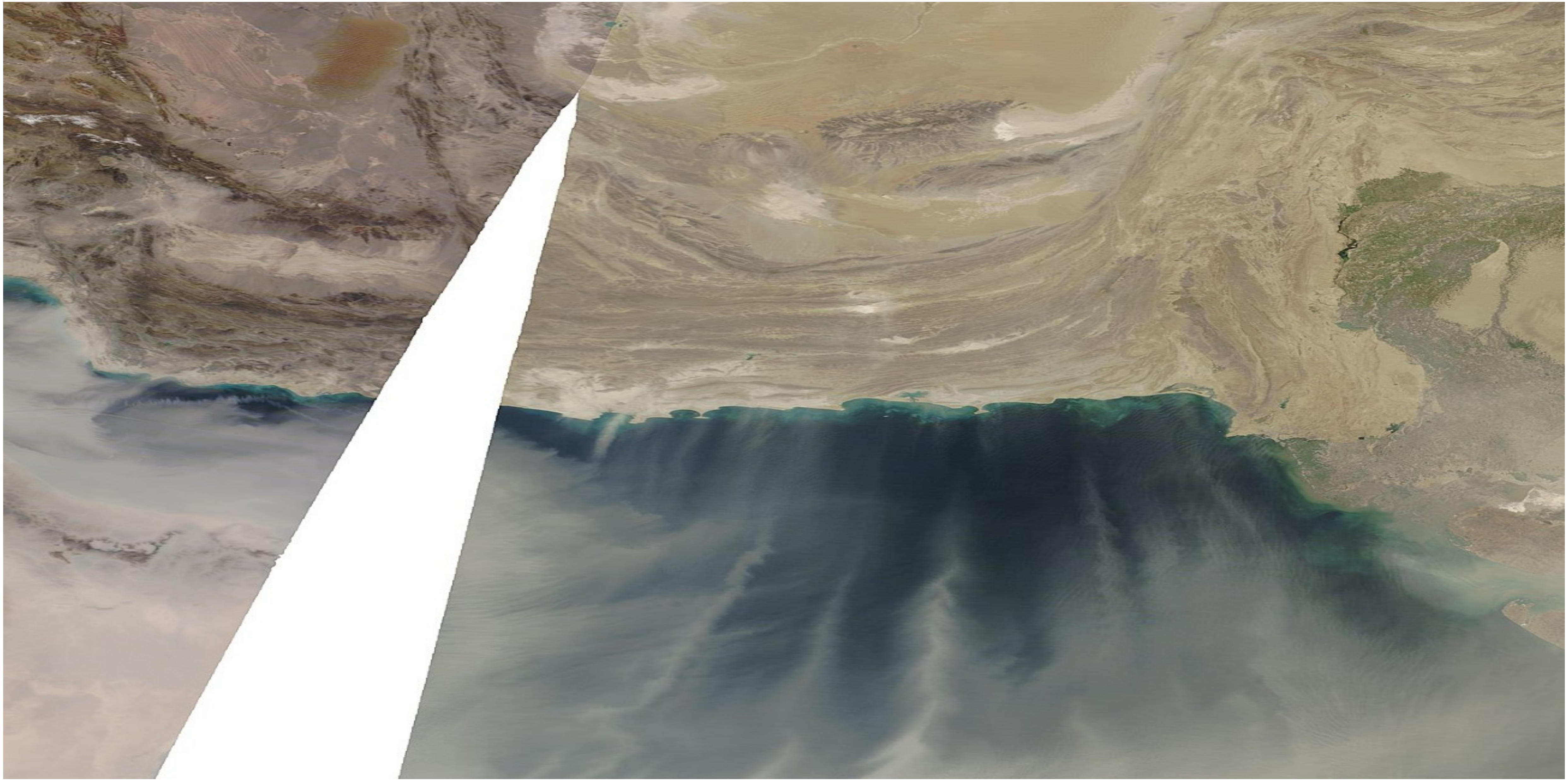




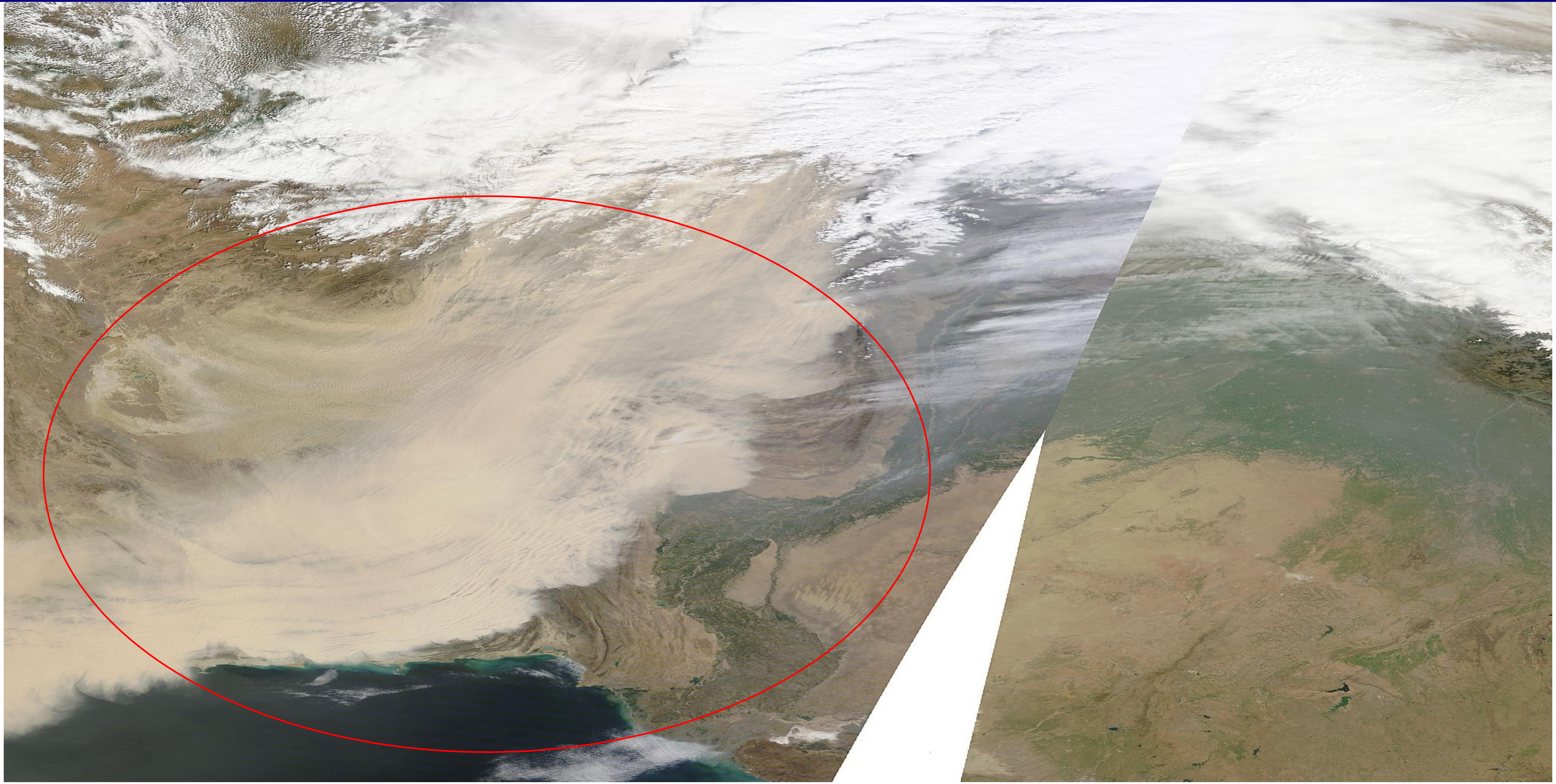
Dust Transport from Hamoun Wetlands



Dust Transport over the Arabian Sea

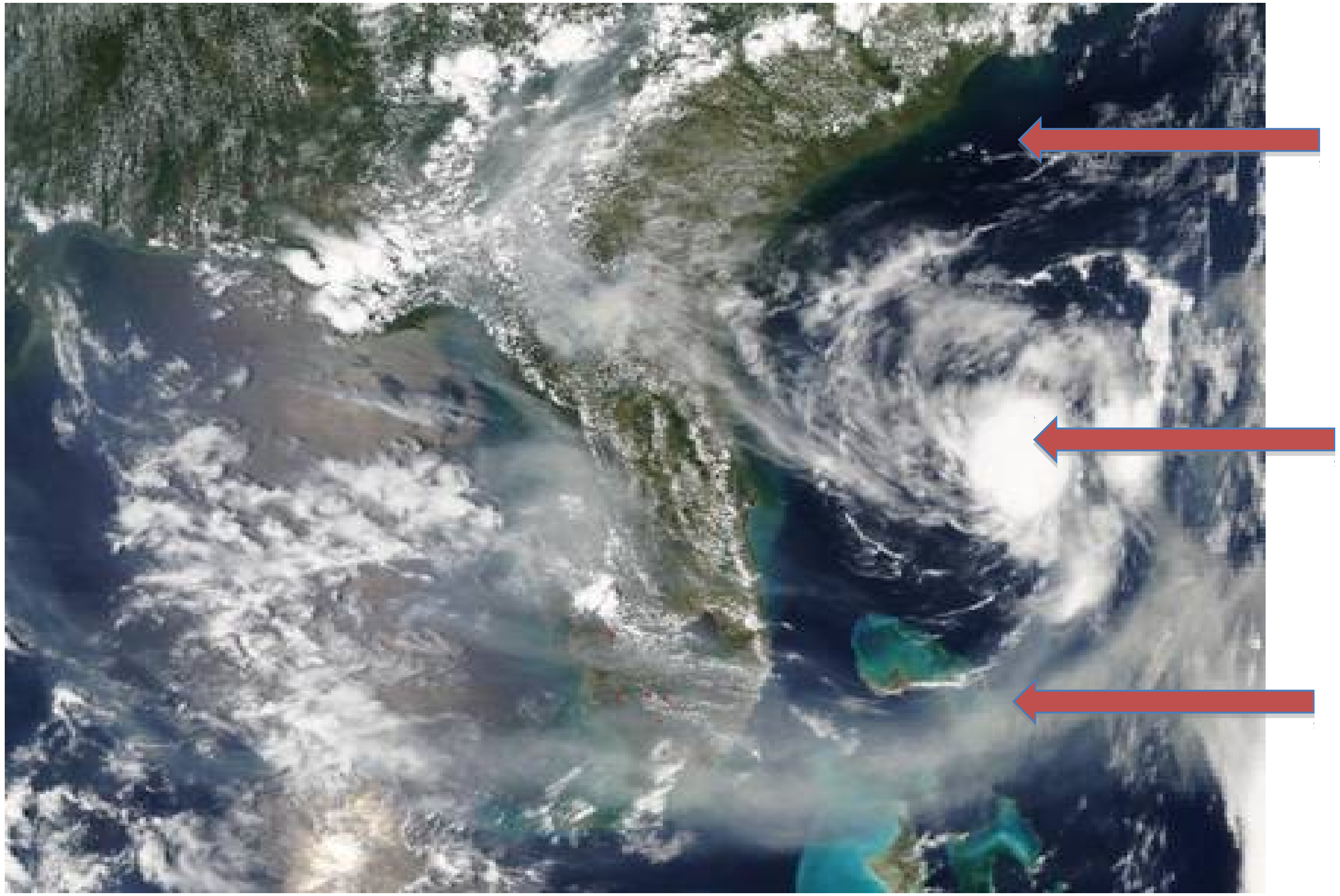


Dust over Iran & Pakistan



Doing More with Satellite Imagery (Climate studies)

If we understand the physics of how particular wavelengths interact with objects in the world we can create images to emphasize what we want to see

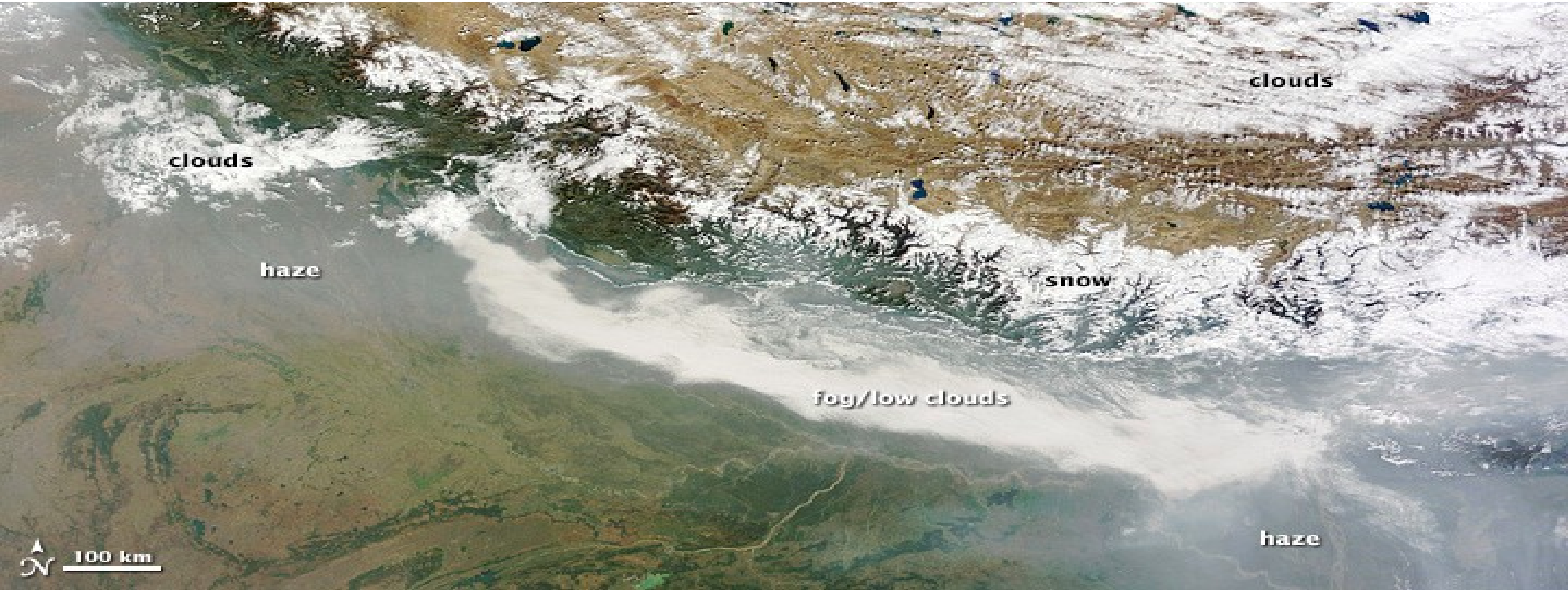


In visible imagery water is dark because it absorbs most of the energy.

Clouds are white because most of the incoming energy is reflected

Pollution is hazy depending upon its absorptive properties

Features In True Color Image (Atmosphere)



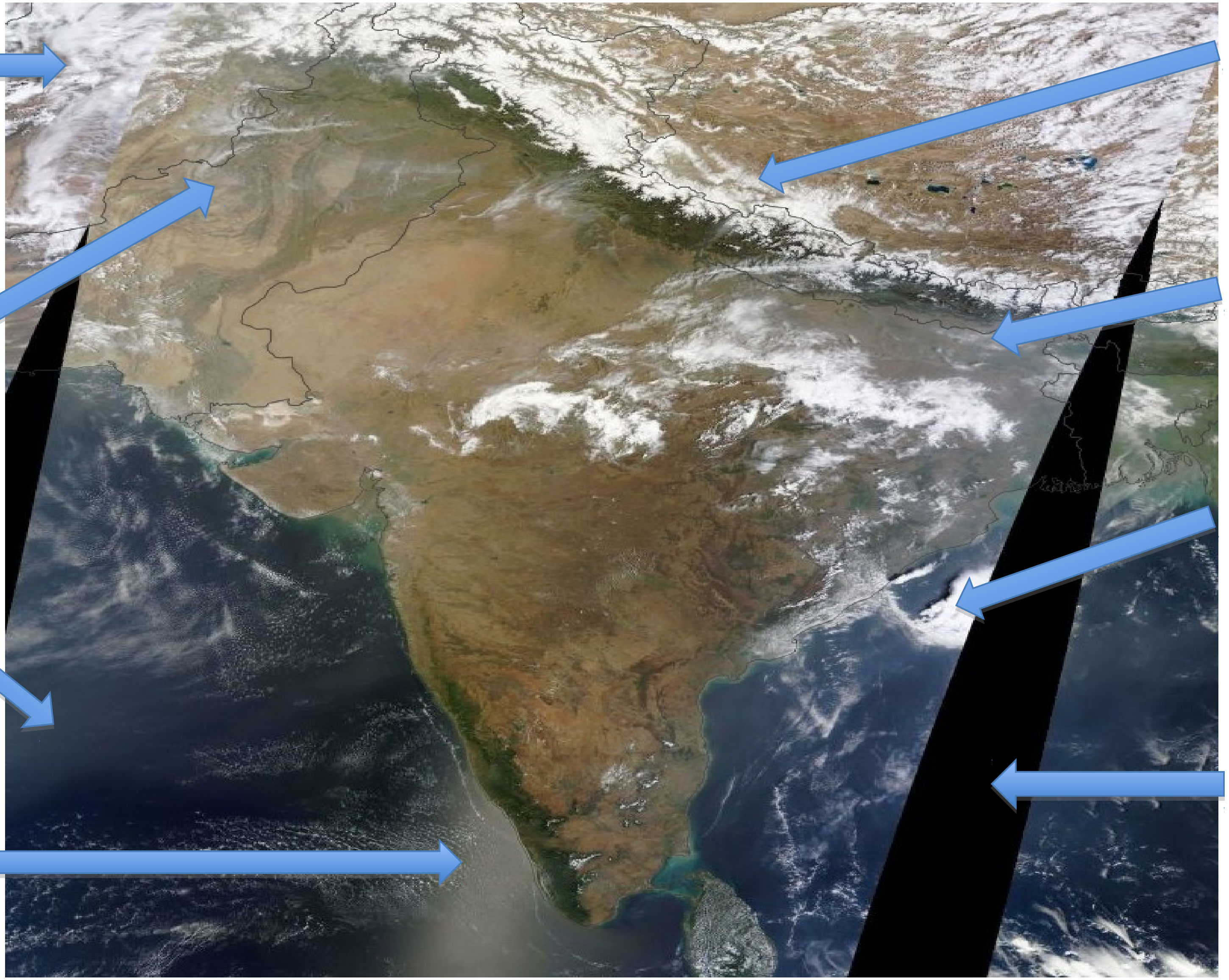
Identify Feature

Clouds

Aerosols over land

Aerosols over ocean

Glint



Snow

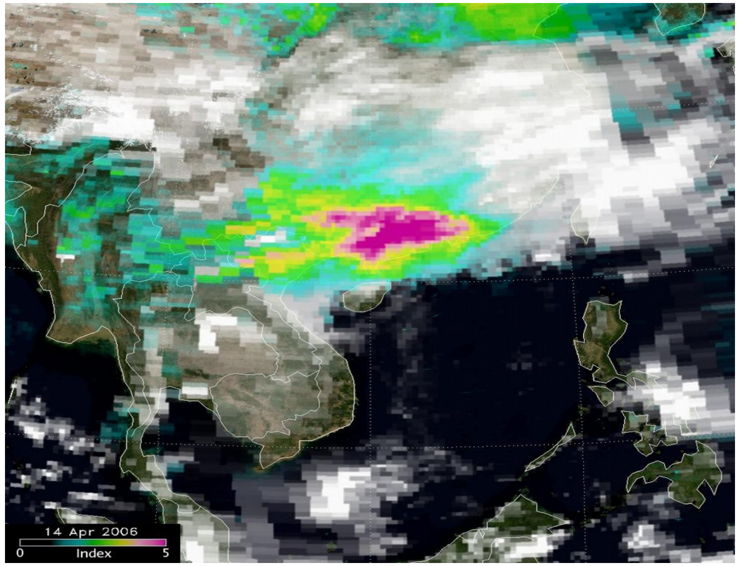
Aerosols over land

Clouds

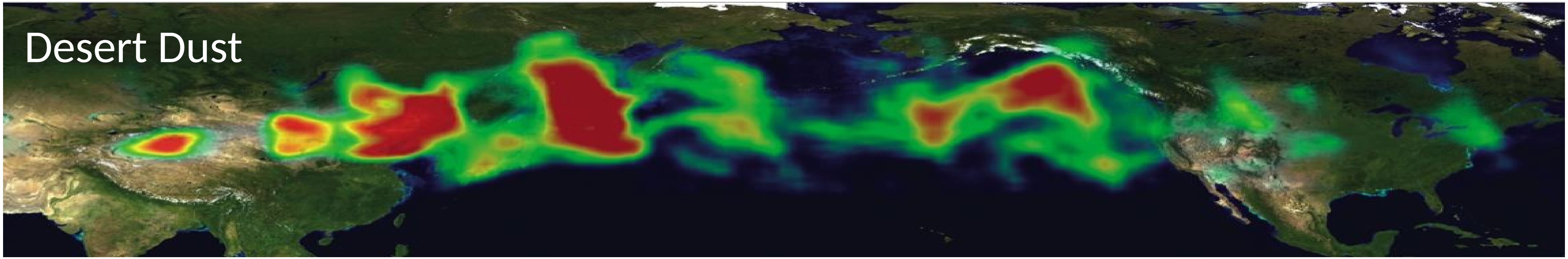
Data collection gap

Aerosol Index

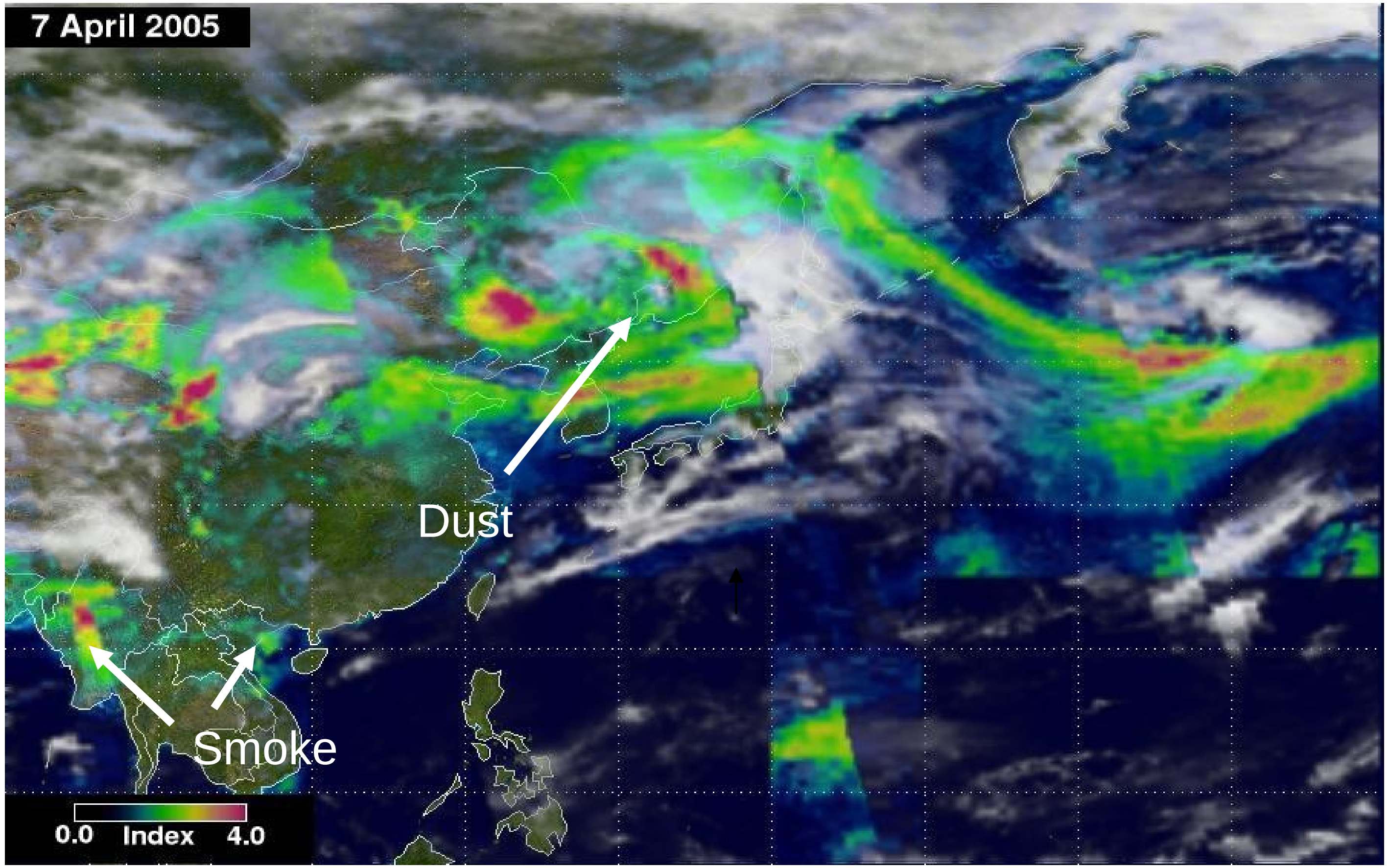
- Validation tool for transport models
- Separation of carbonaceous from sulfate aerosols
- Identification of aerosols above PBL (i.e., PBL aerosols are not detectable by AI)
- Tracking of aerosol plumes above clouds and over ice/snow

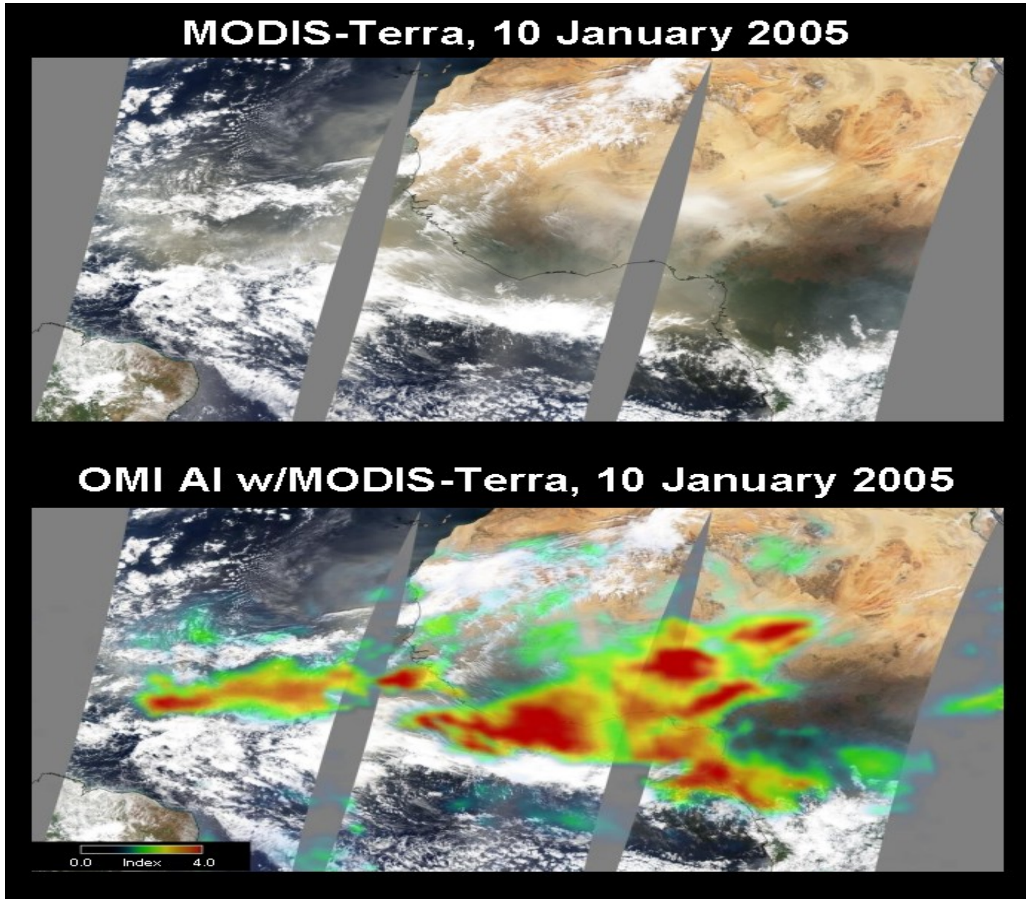


Aerosol s over clouds:
April 14, 2006



Aerosol Index





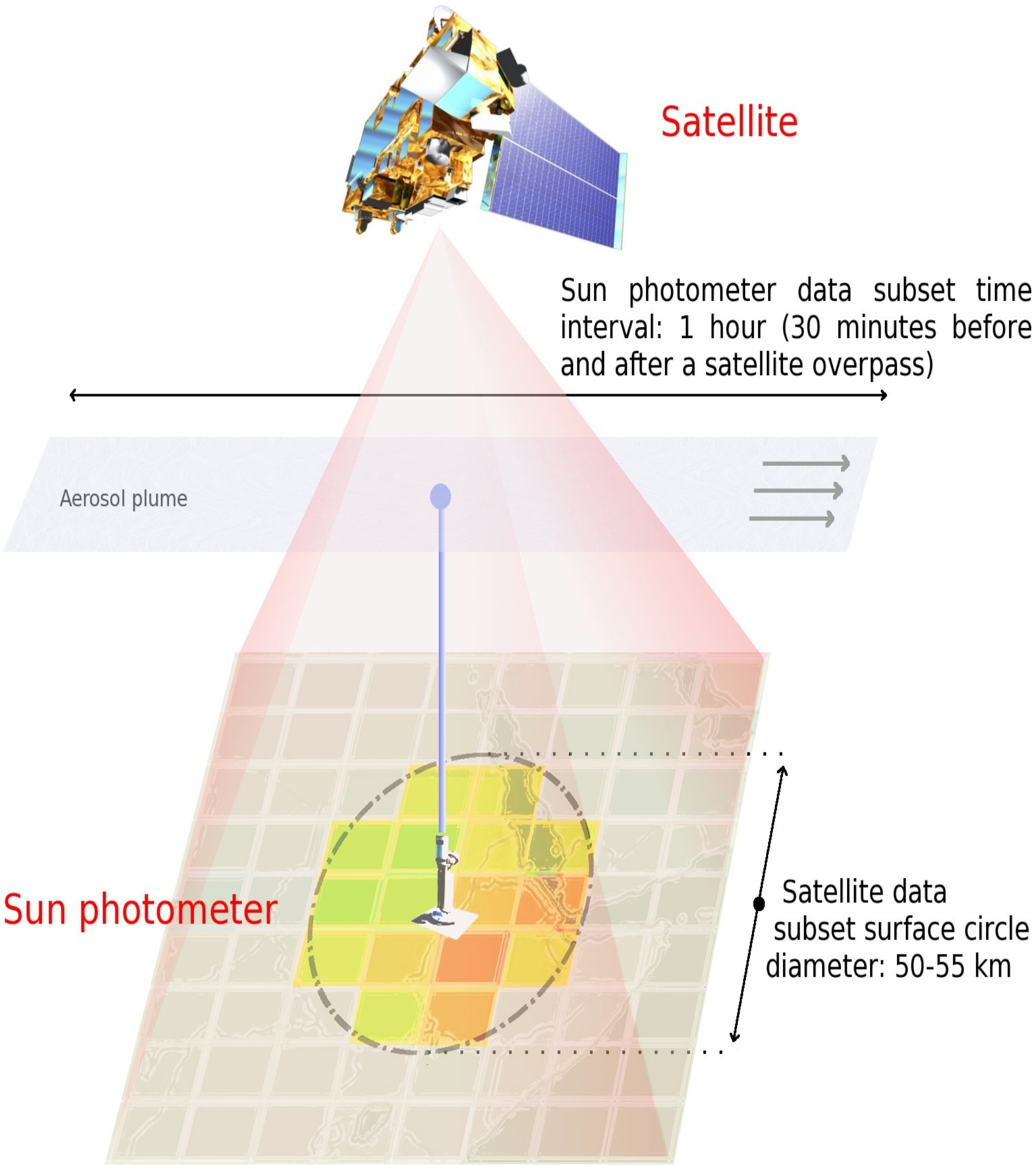
Aerosol Transport across the Oceans in terms of the Absorbing Aerosol Index

Satellite & Ground data validation

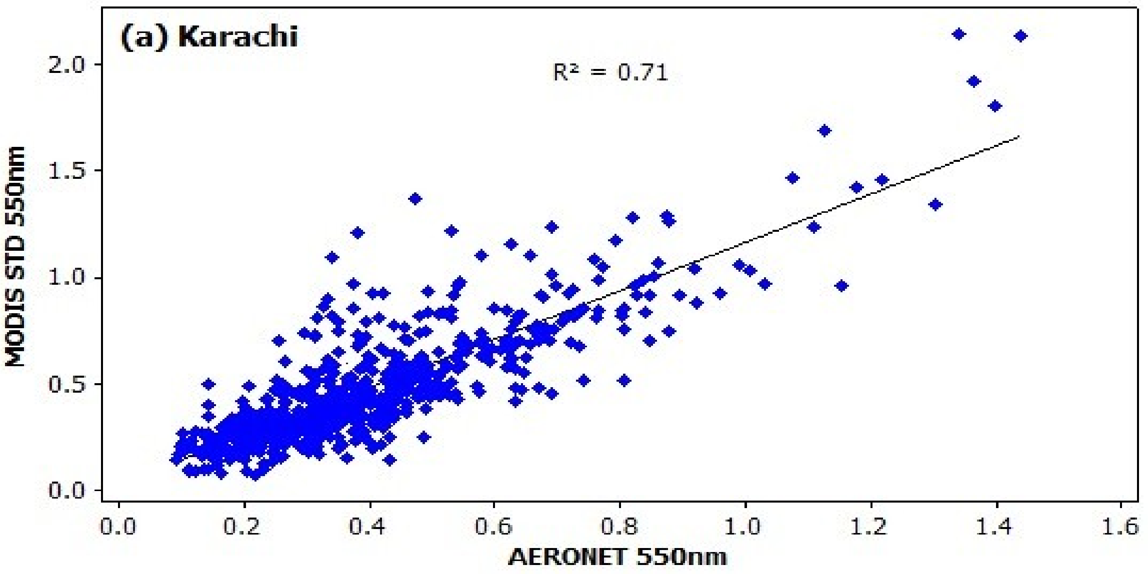
- An intercomparison of AOD values from different sensors is necessary if a long-term database for climatological studies is to be established
- To improve the accuracy and the coverage achievable with a single sensor
- AERONET AOD values (at 500 nm) were interpolated at common wavelength of 550 nm, using power law:

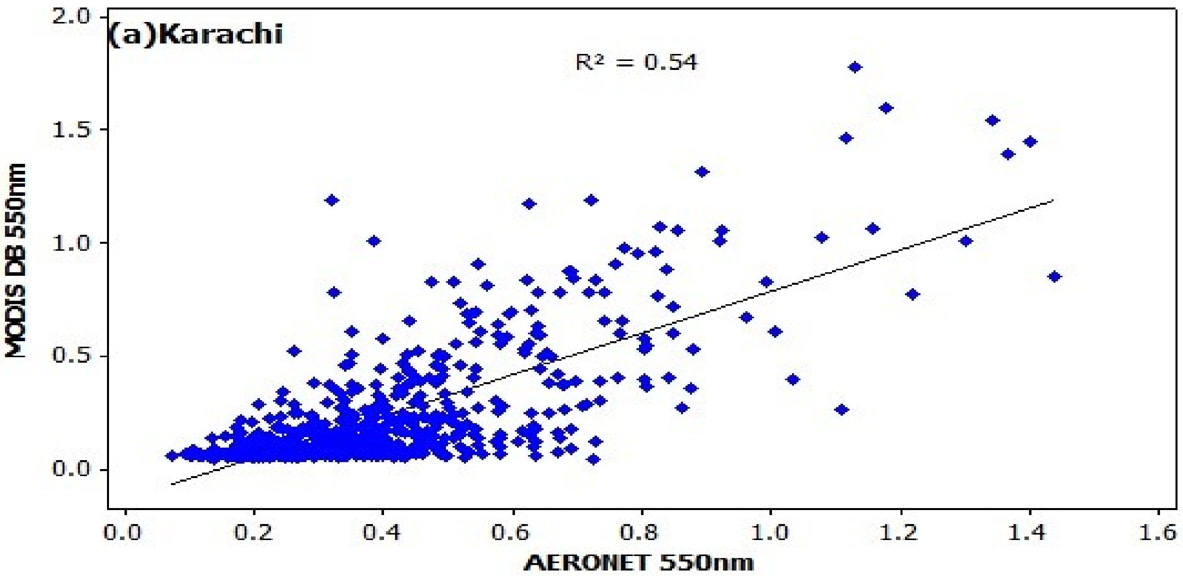
$$AOD_{550nm} = AOD_{500nm}\left(\frac{550}{500}\right)^{-\alpha}$$

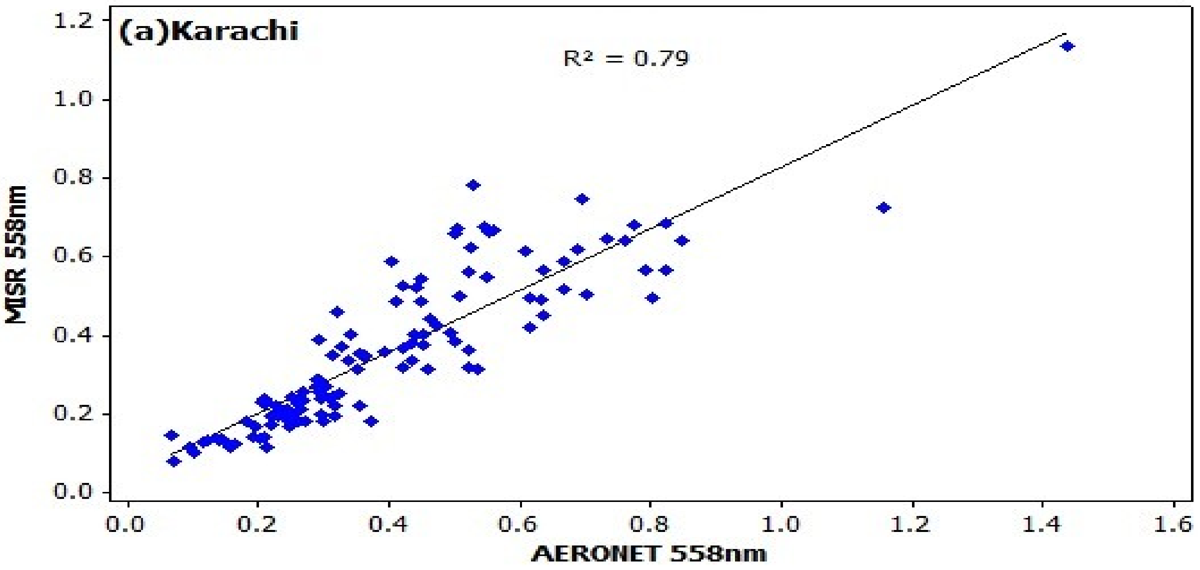
where α is the (440–870 nm) Angstrom exponent

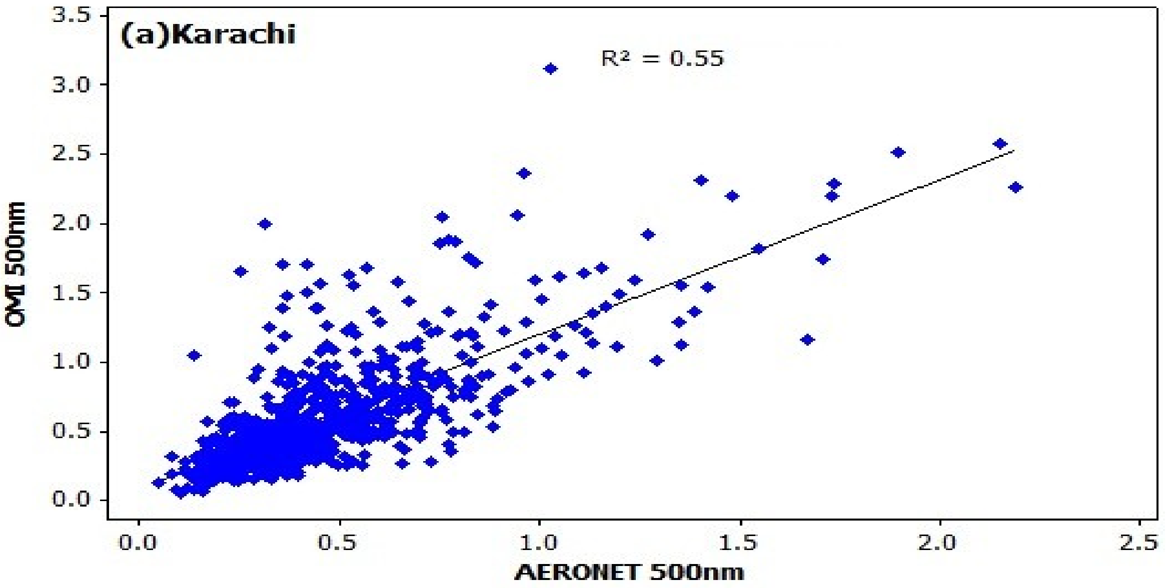


Intercomparision of Satellite and AERONET AOD

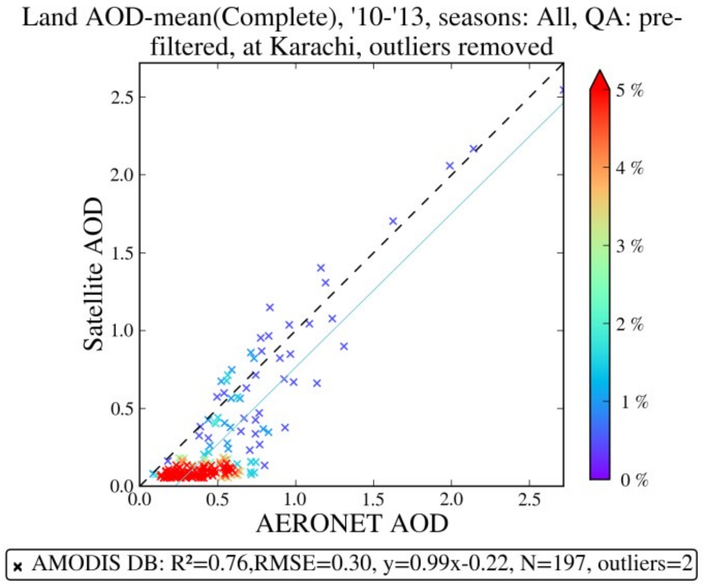


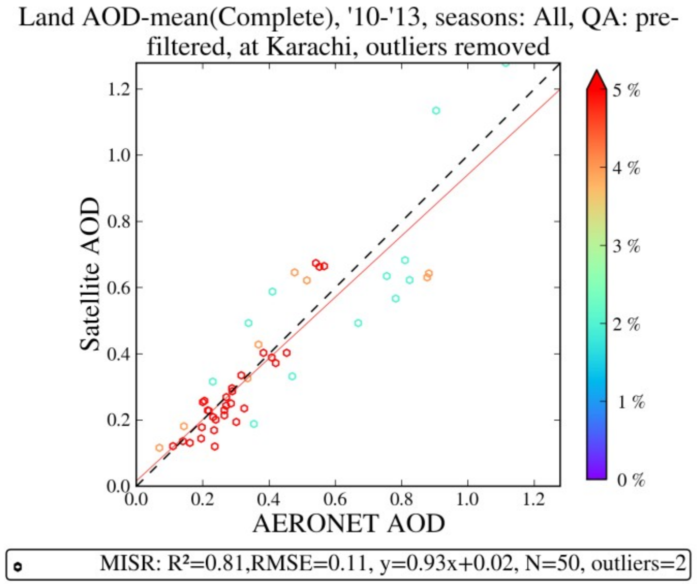


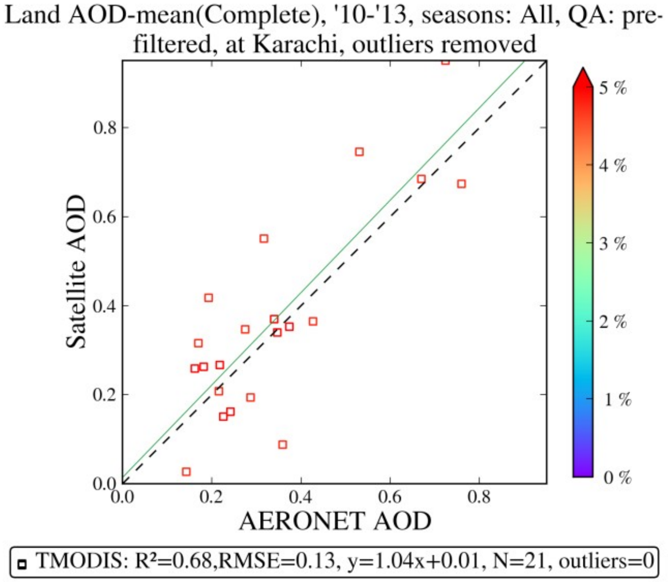


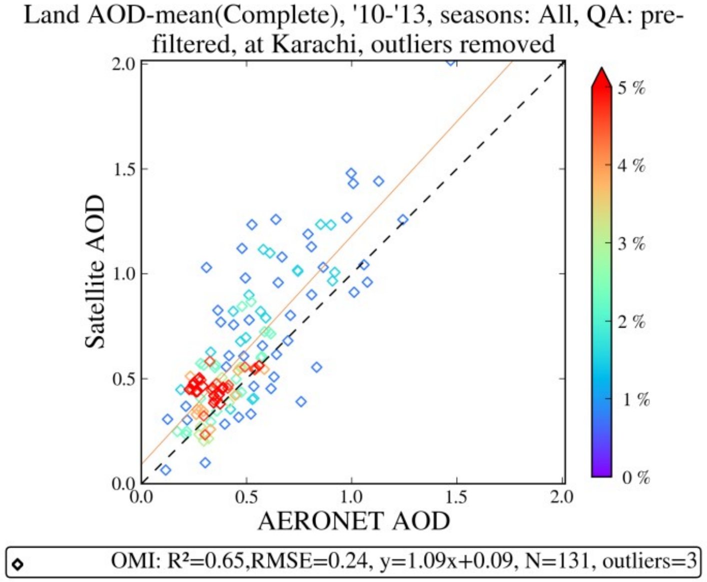


Intercomparision of Satellite and AERONET AOD

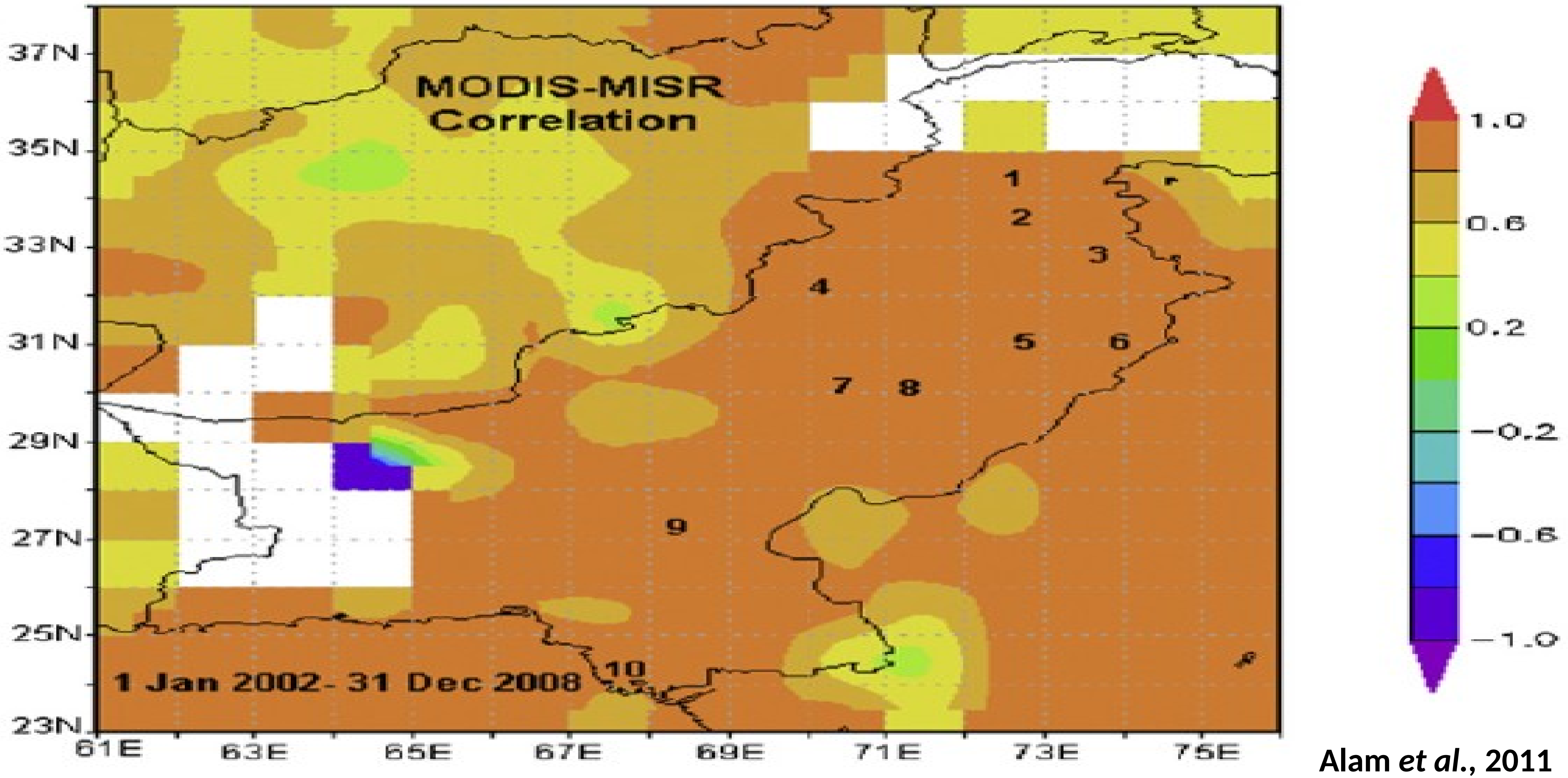






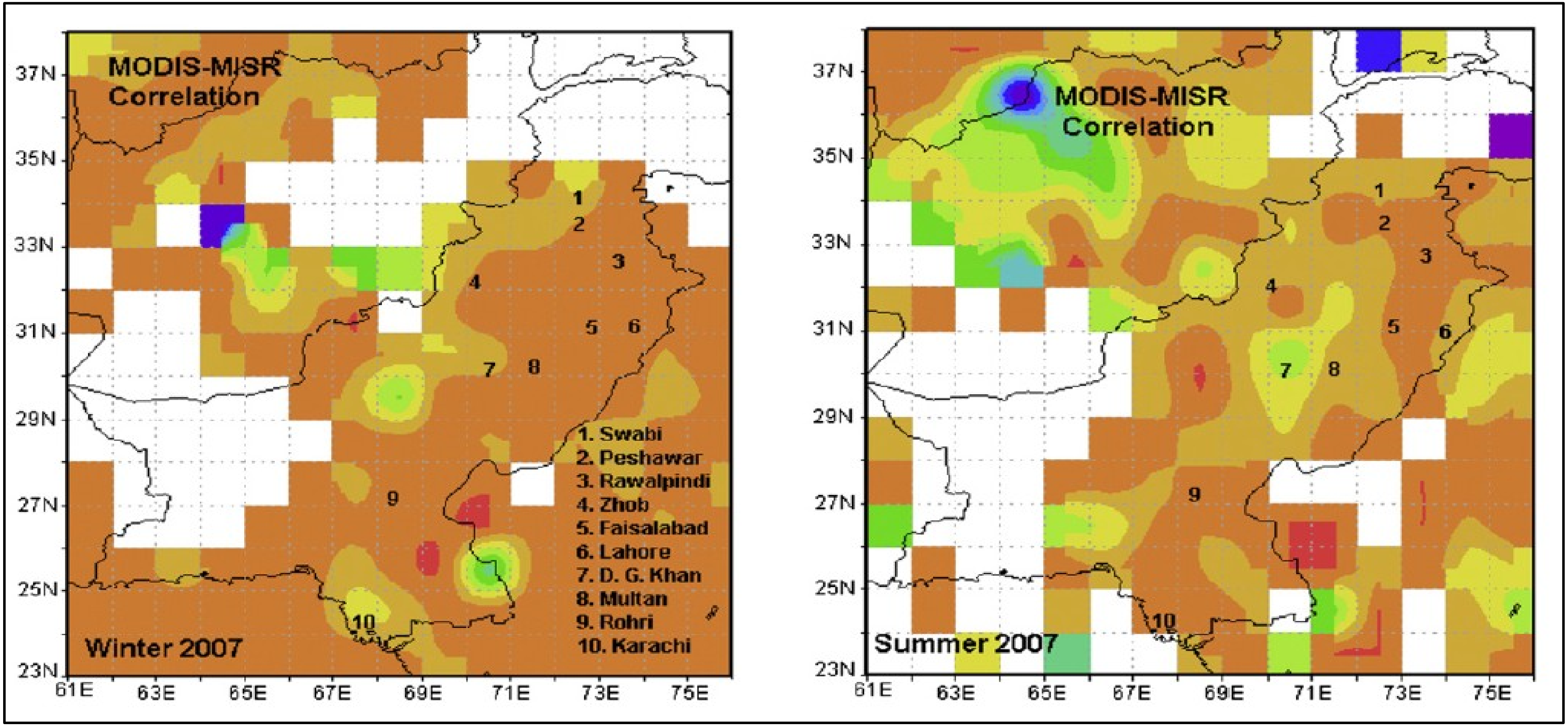


MODIS vs. MISR



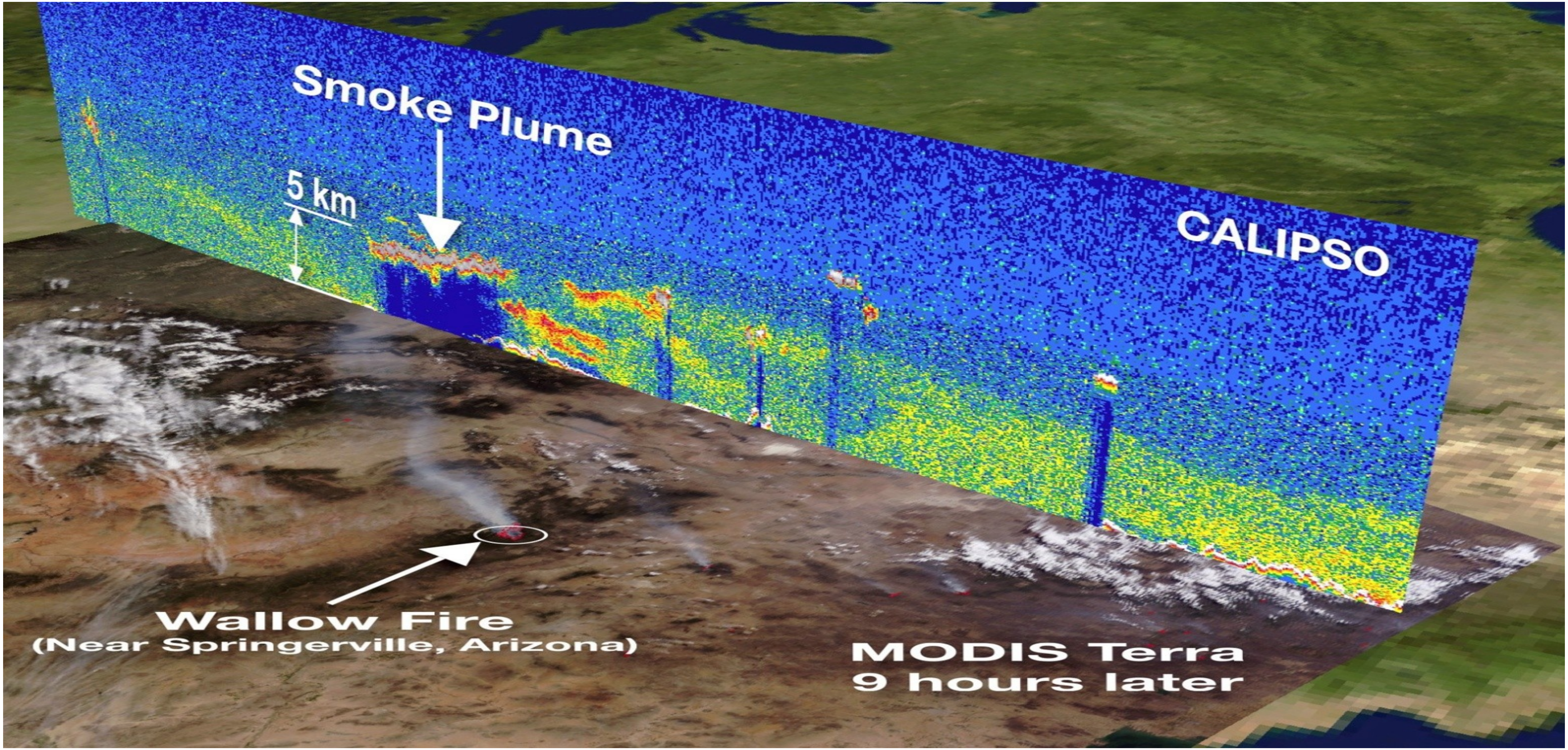
Alam *et al.*, 2011

MODIS vs. MISR



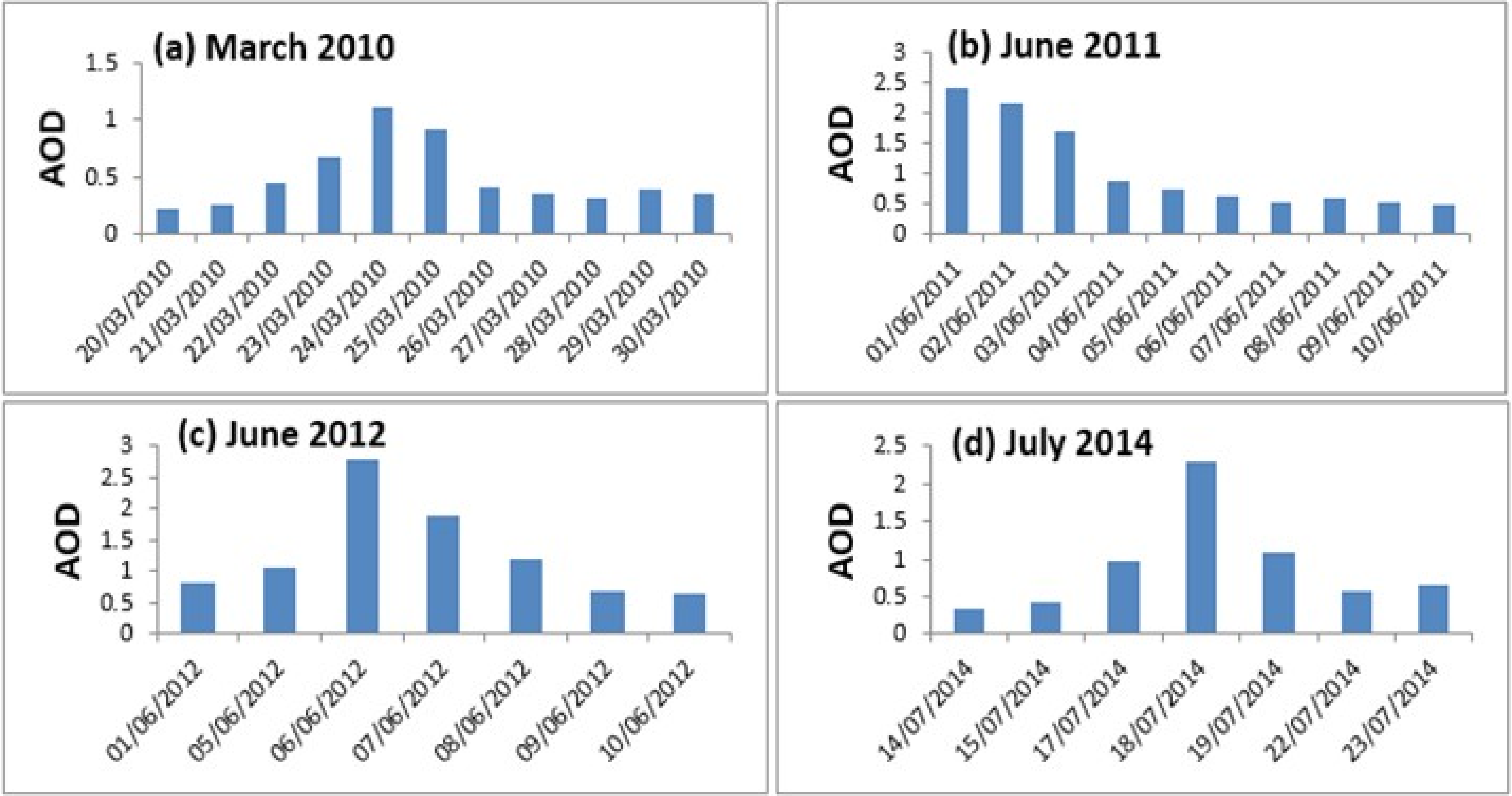
Alam *et al.*, 2011

Satellite Data Validation

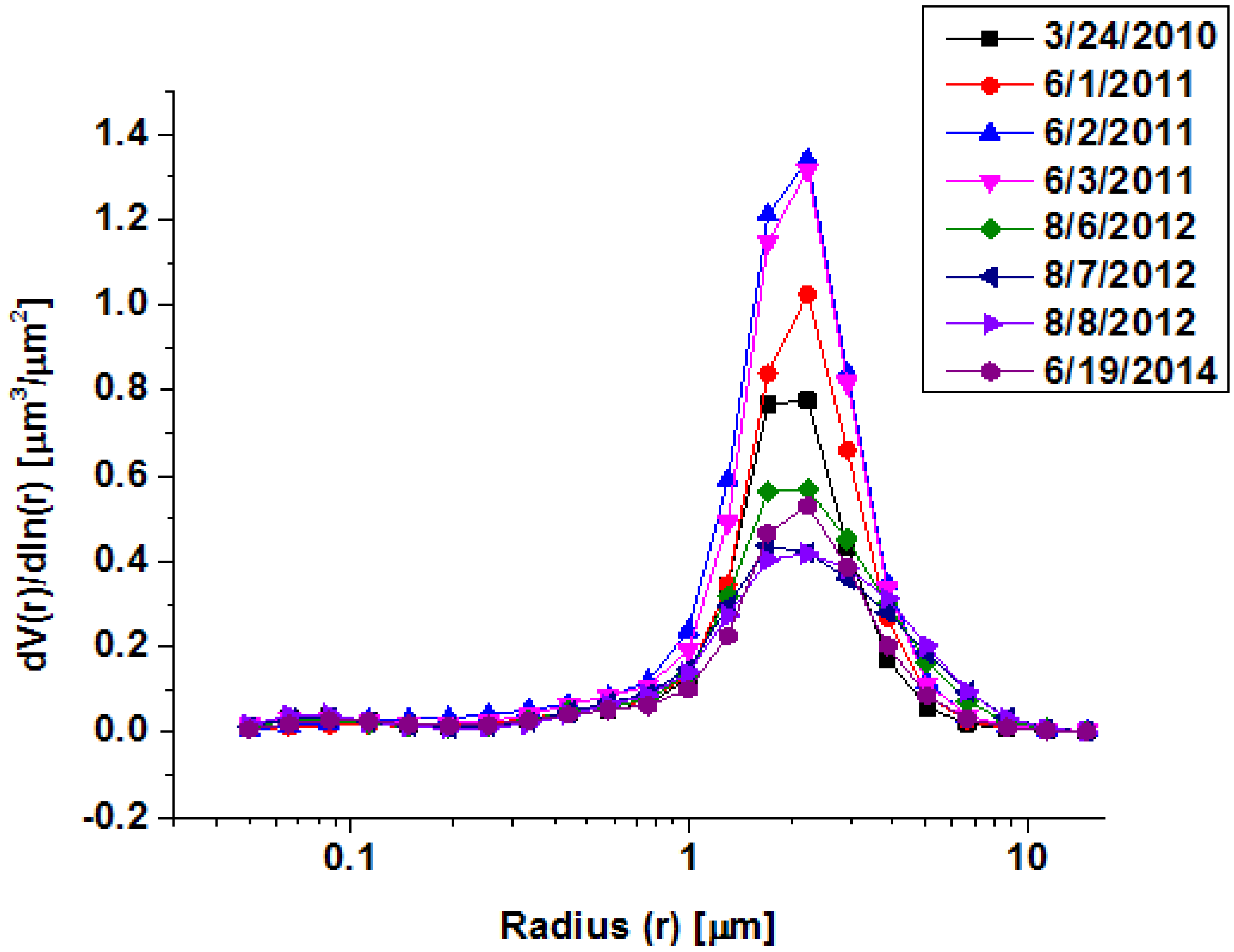


Dust Characteristics over Karachi

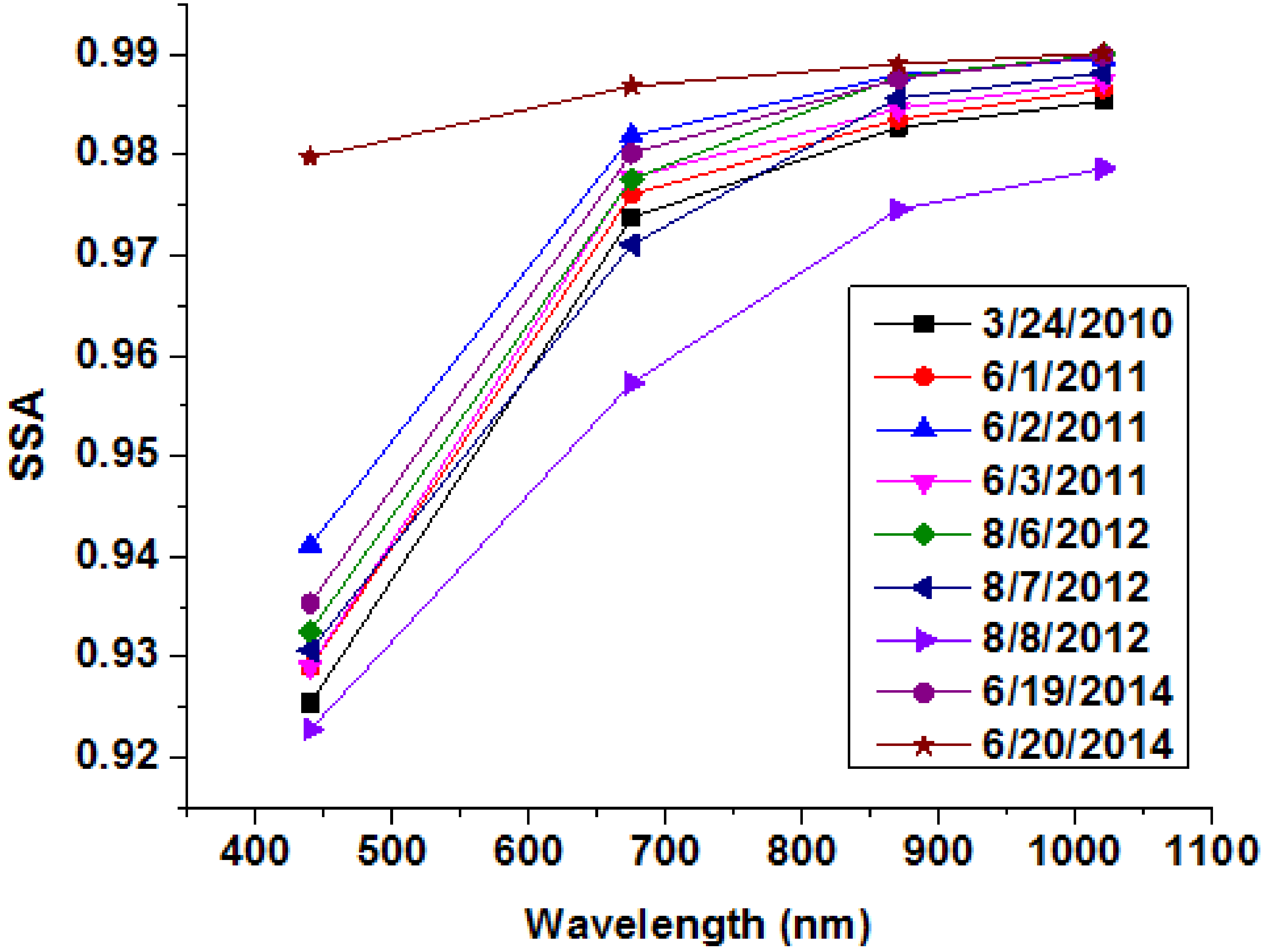
Variation in Aerosol Optical Depth during dusty and non dust days



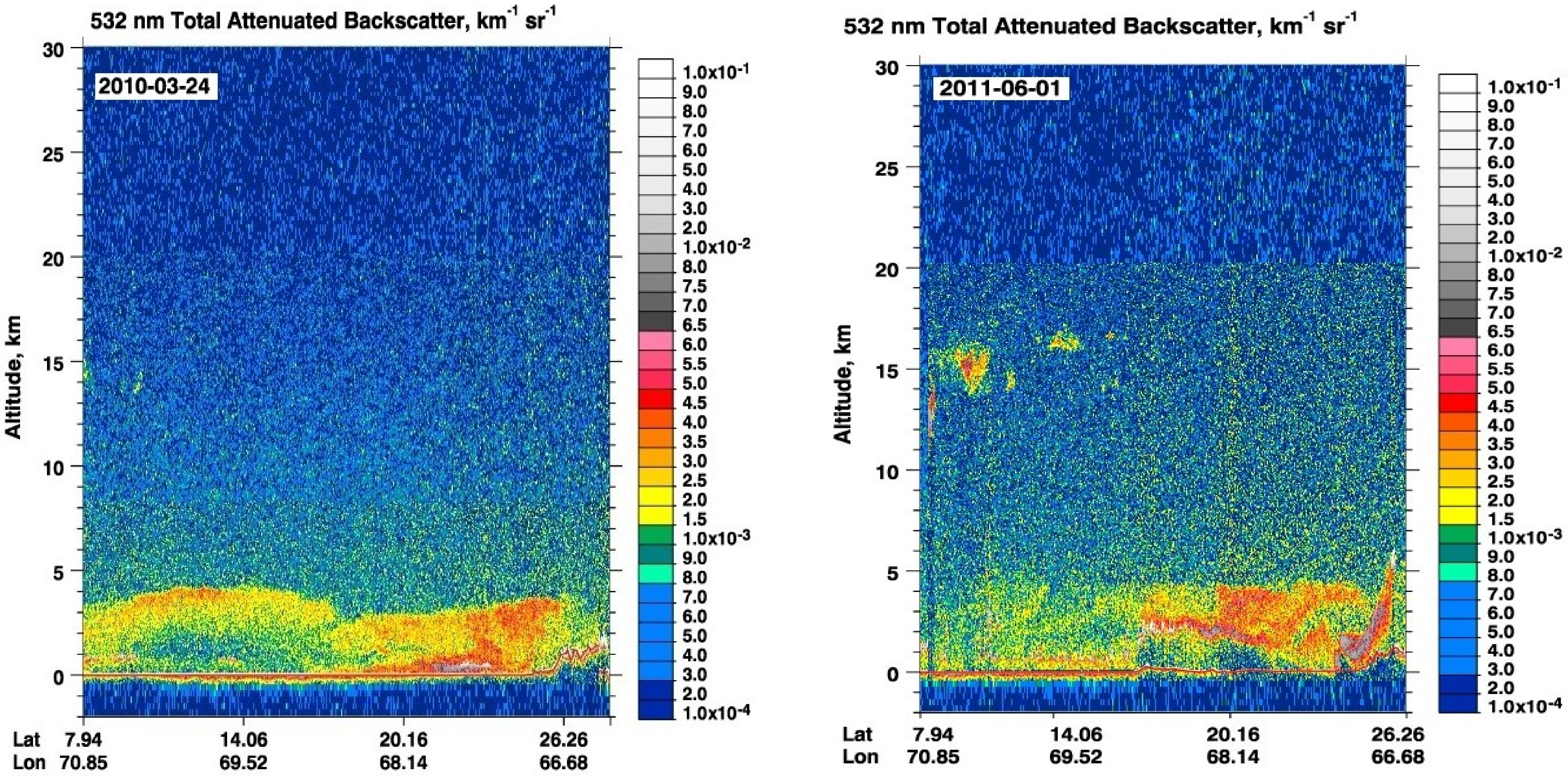
Volume Size Distribution



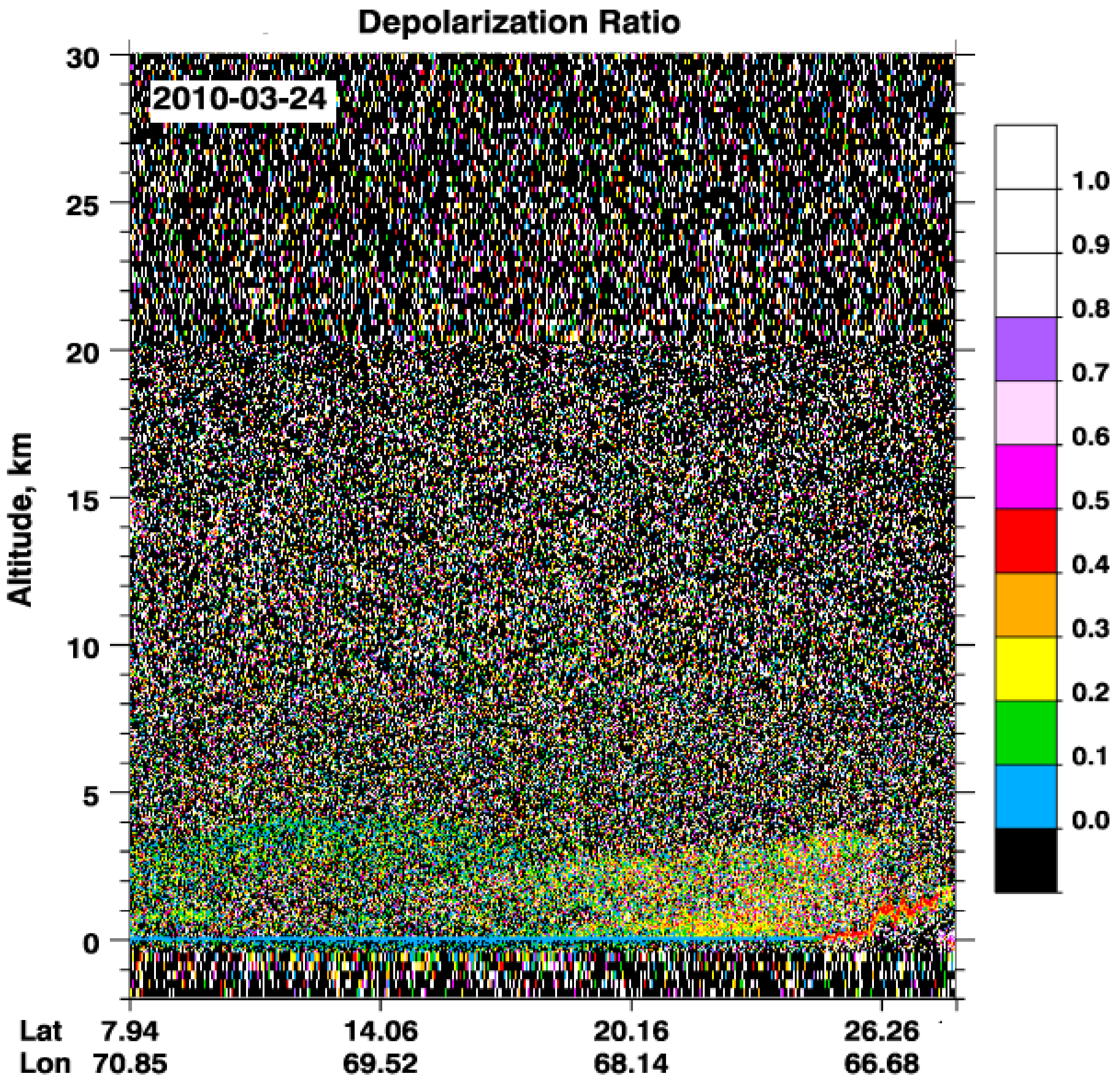
Single Scattering Albedo

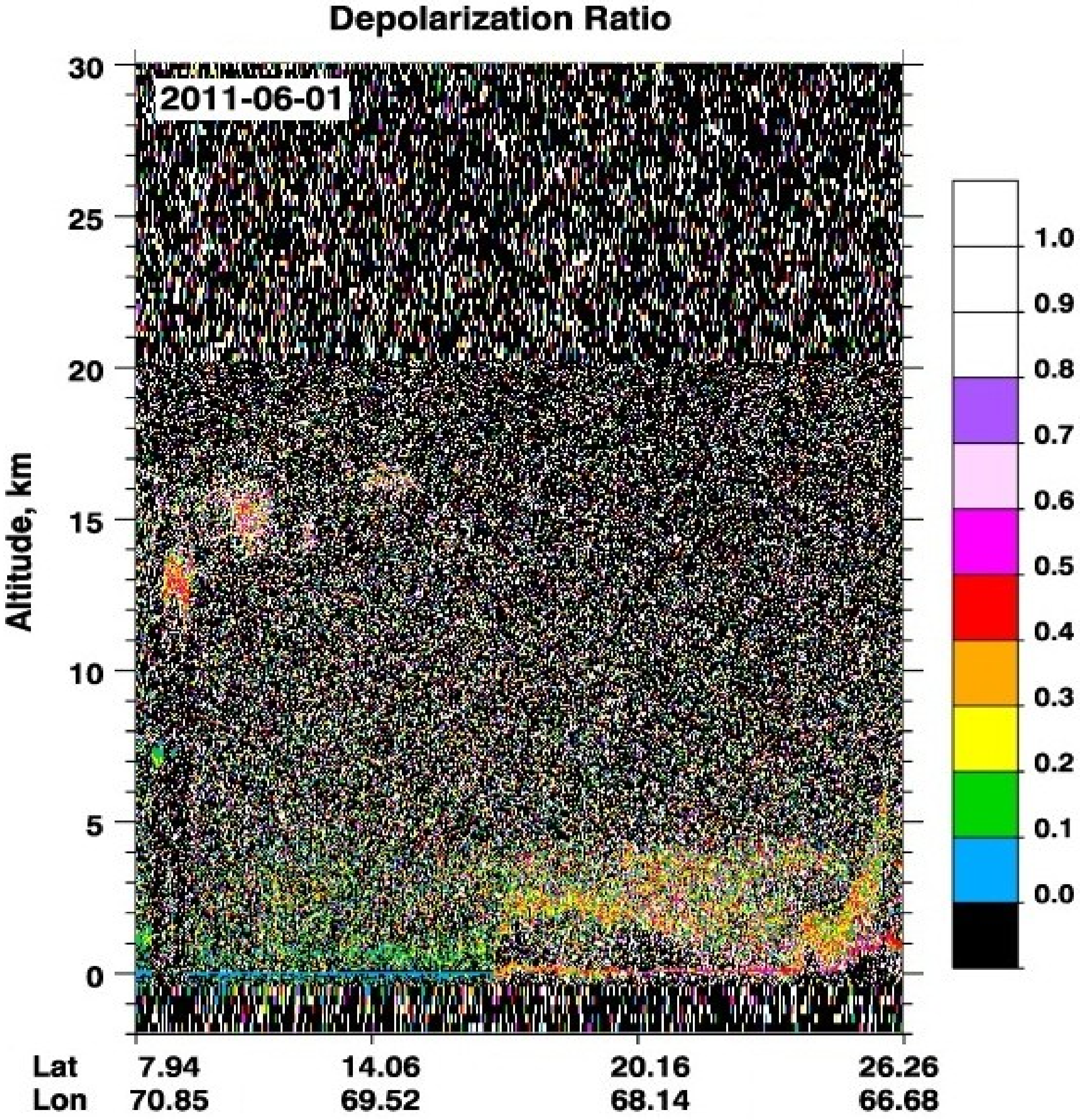


CALIPSO Total Attenuated Backscatter

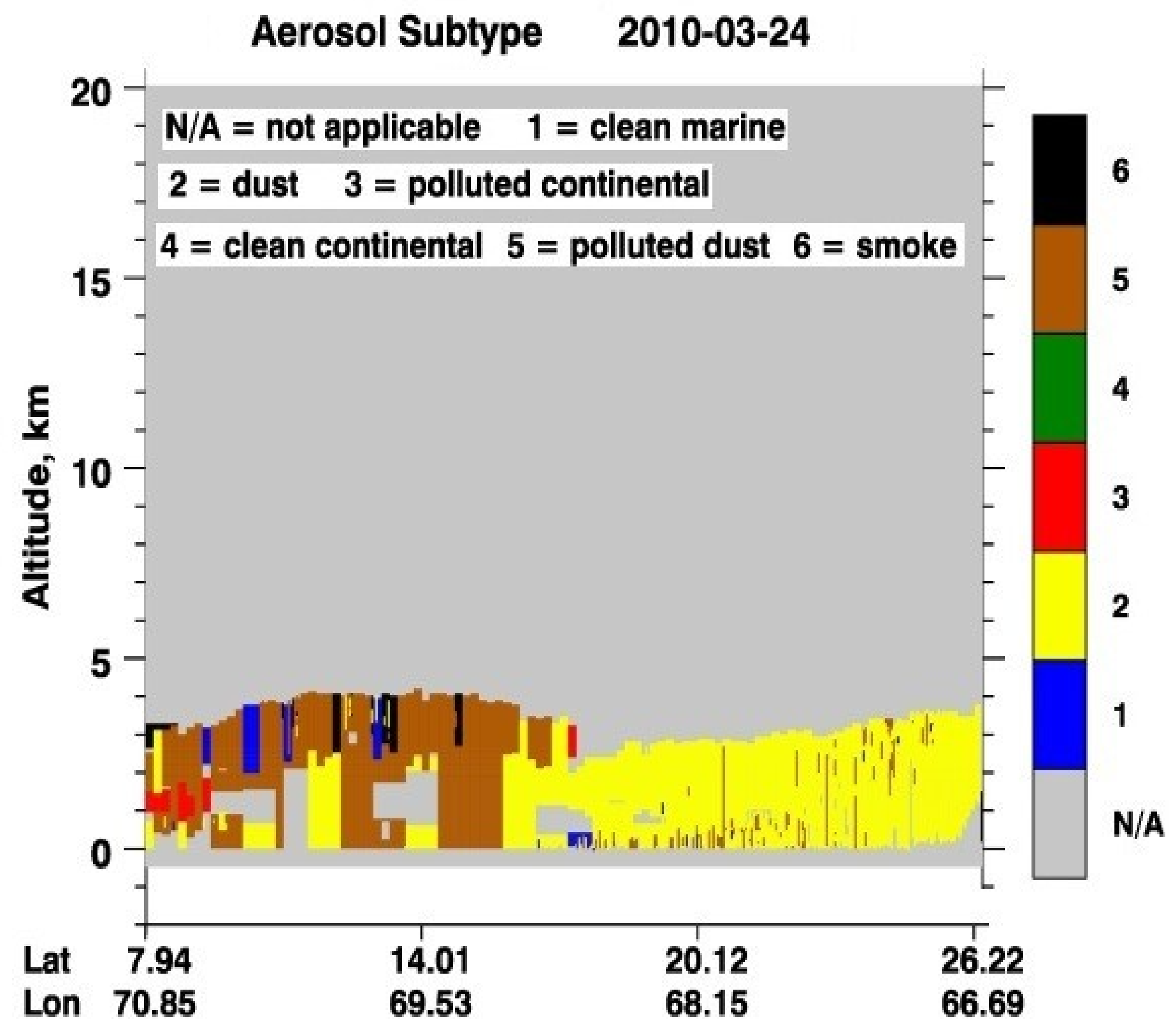


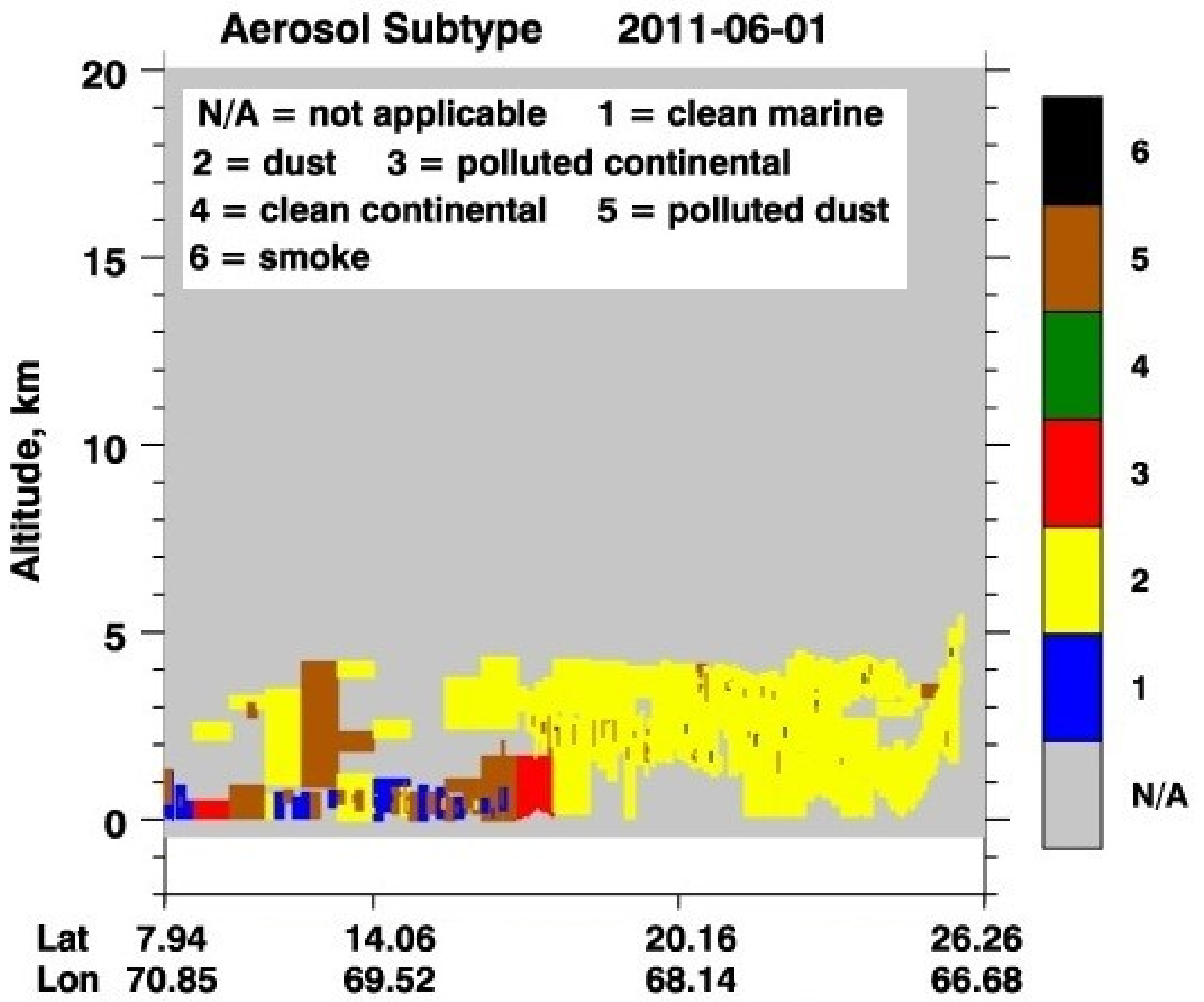
CALIPSO: Depolarization Ratio



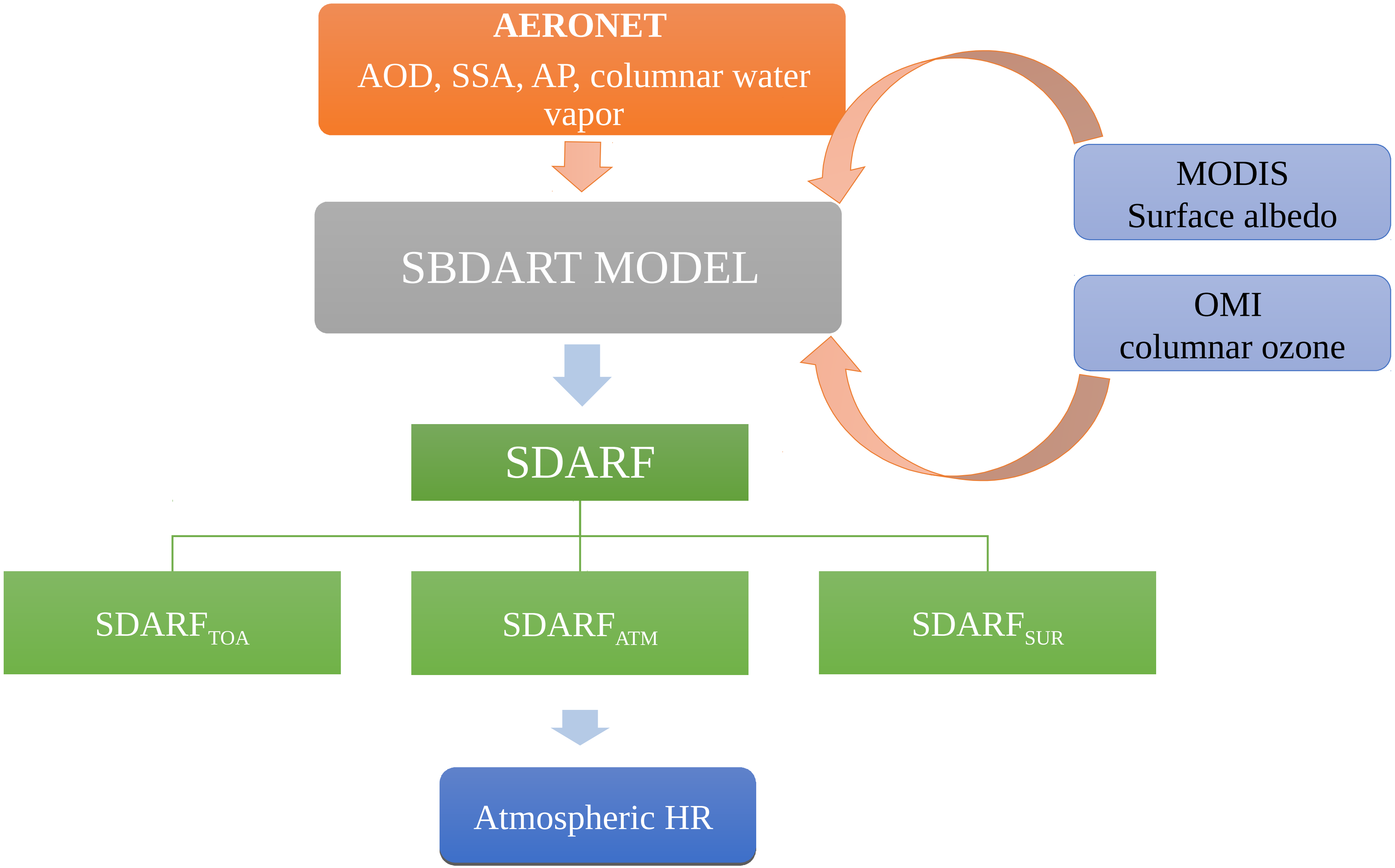


CALIPSO: Aerosol Classification

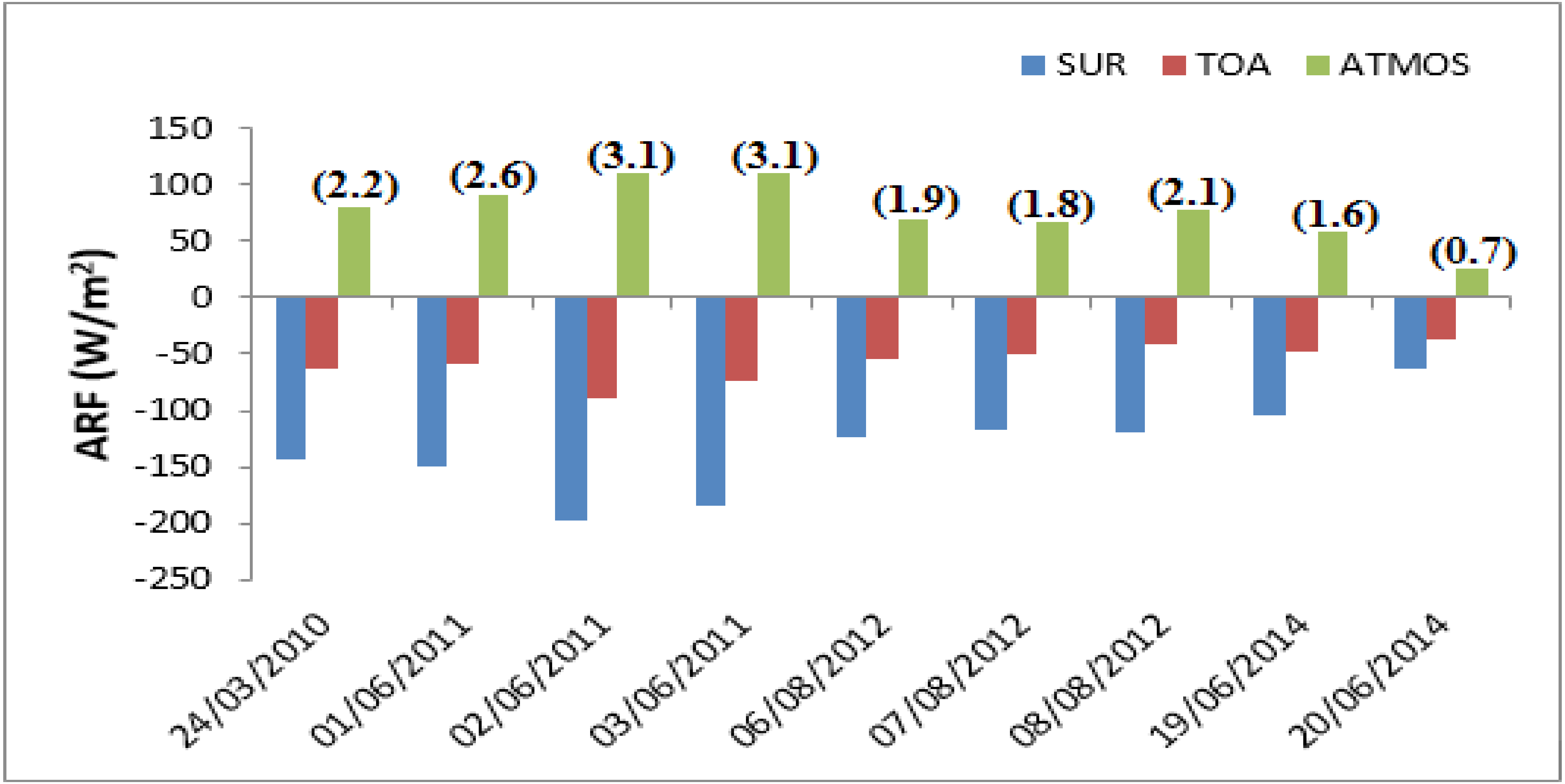




Schematic Diagram of Shortwave Radiative Forcing using SBDART Model



Aerosol Radiative Forcing and Heating Rates

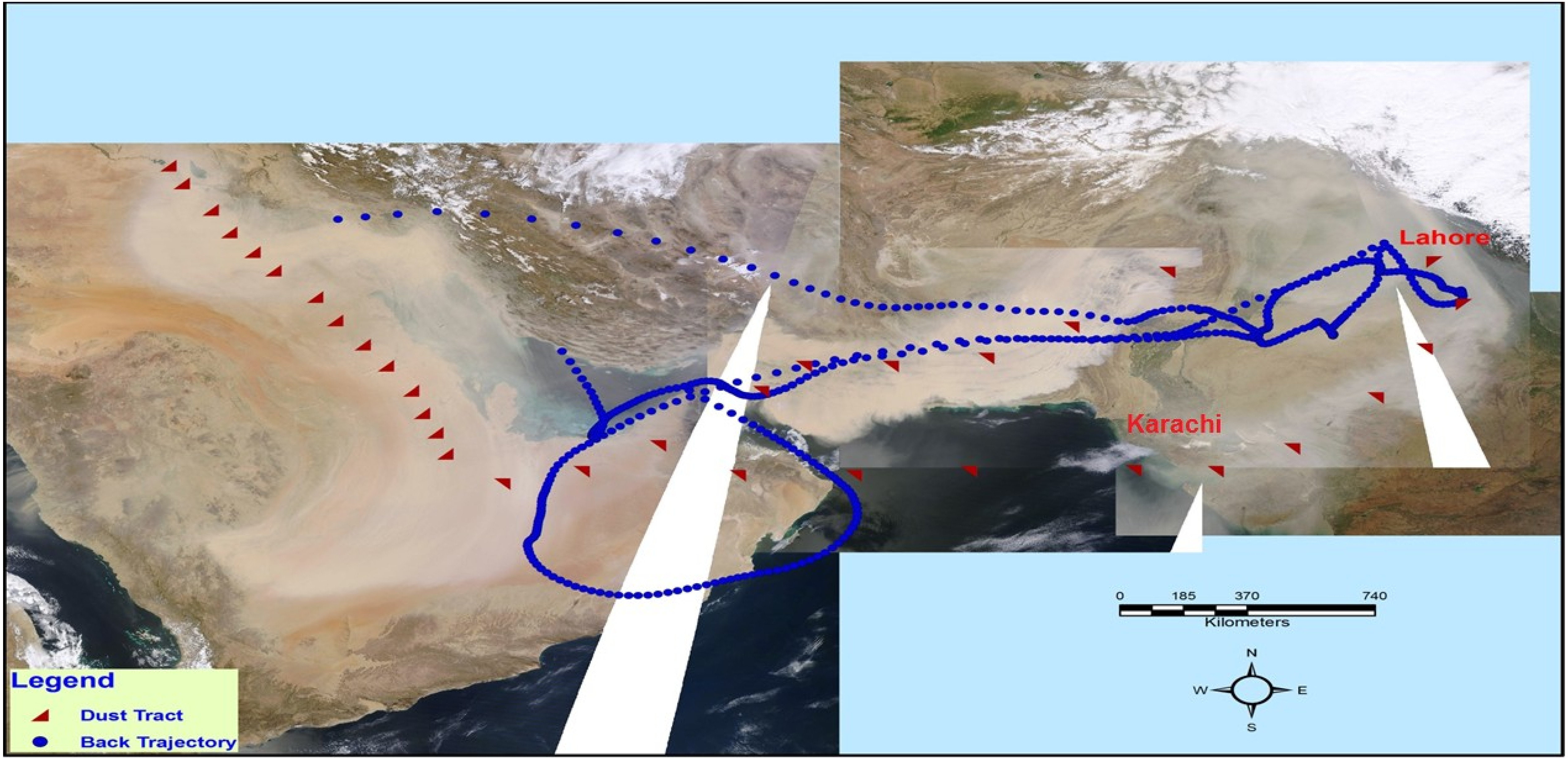


Dust Characteristics over the Middle East & Southwest Asia

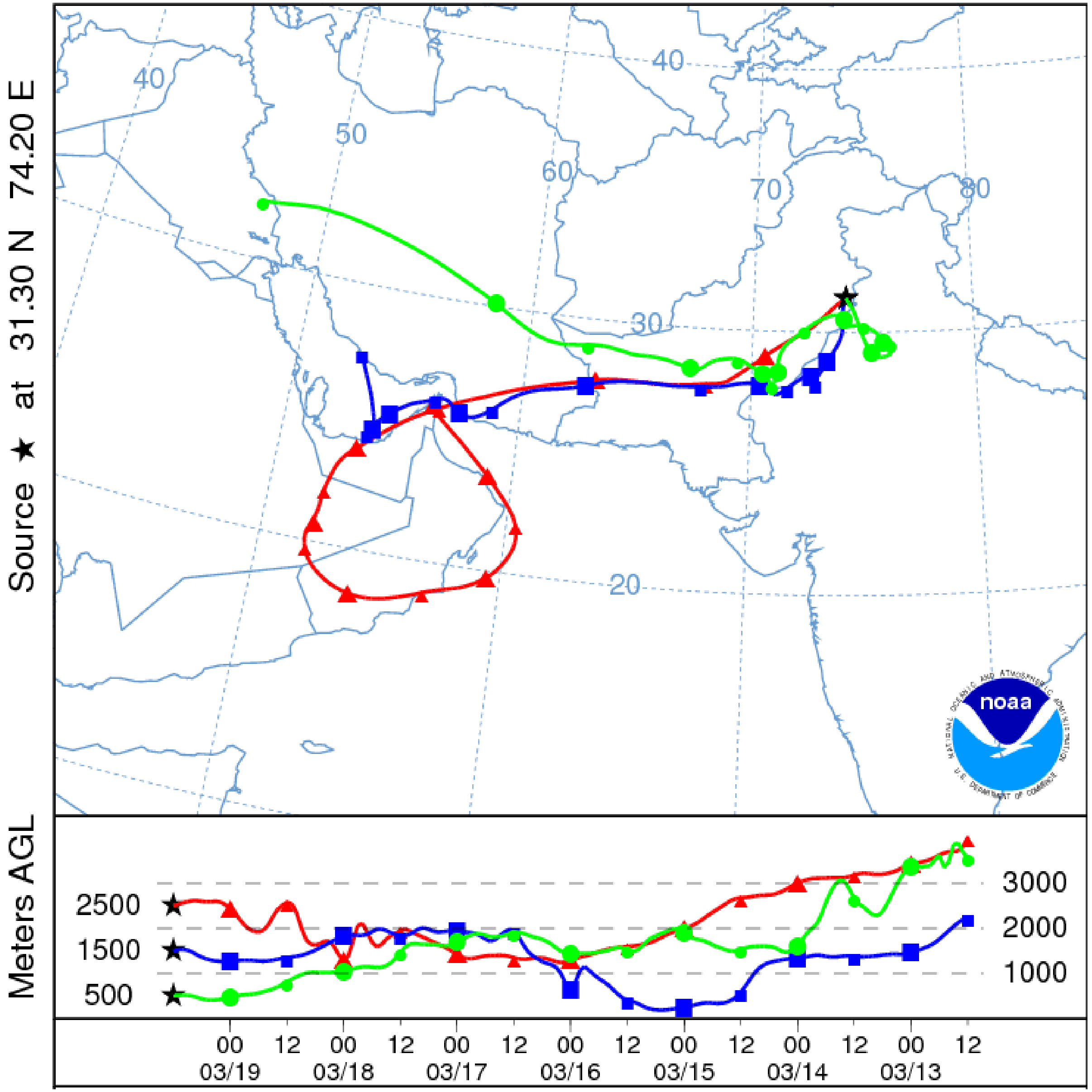
Alam, K., Trautmann, T., Blaschke, T., Subhan, F. (2014). Changes in aerosol optical properties due to dust storm in the Middle East and Southwestern Asia. Remote Sensing of the Environment,143, 216-227

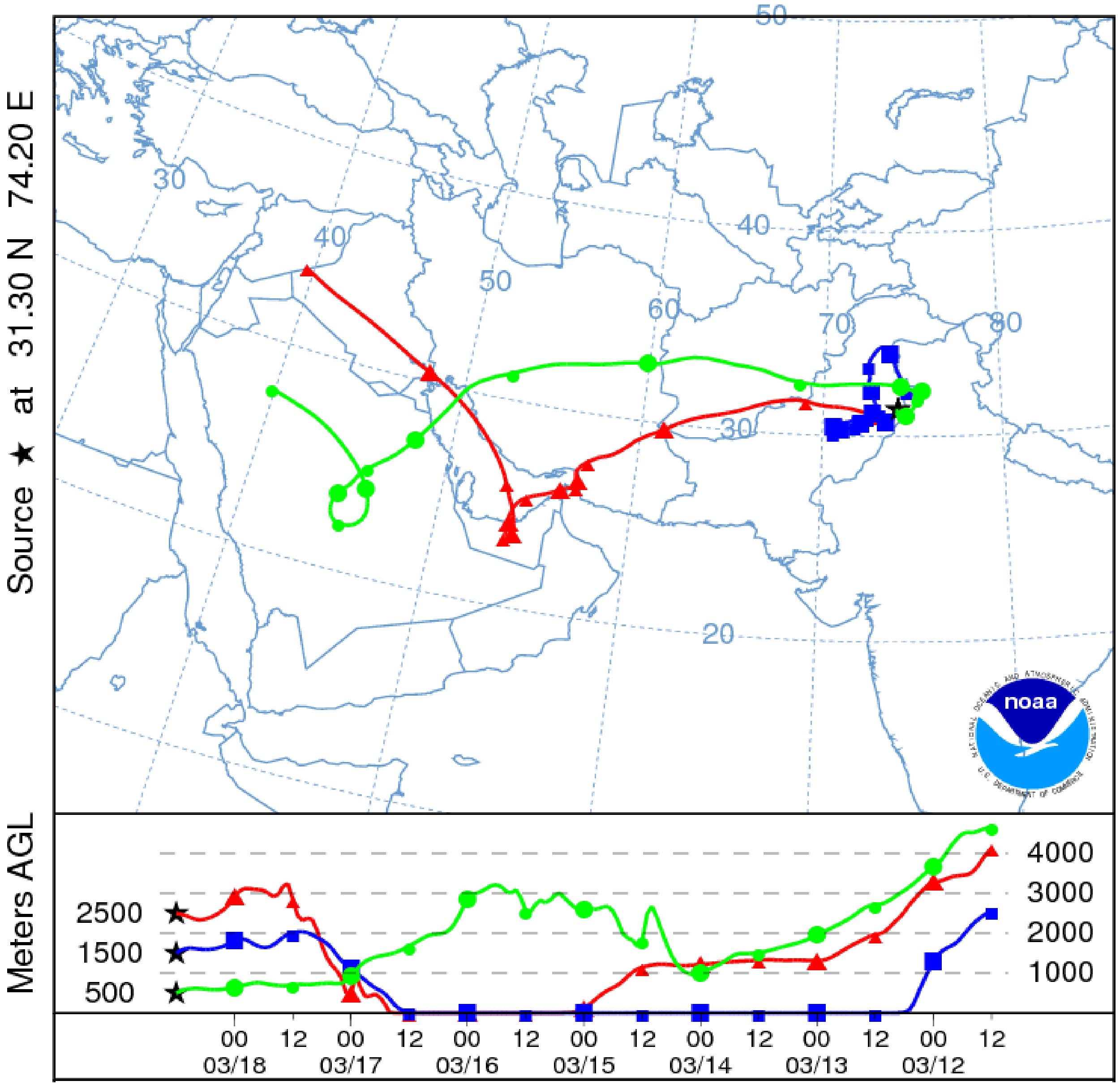
❖ Dust in Middle East and Southwest Asia

Formation of Dust events and Meteorological situation

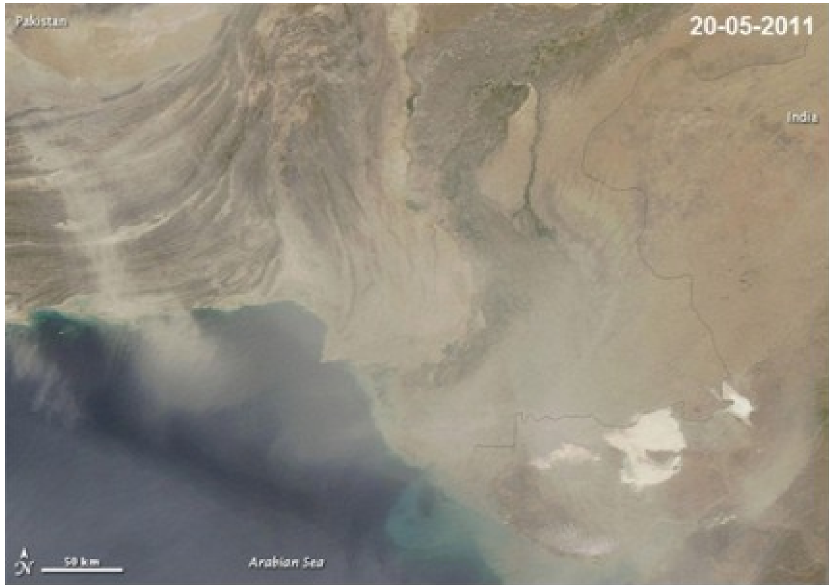


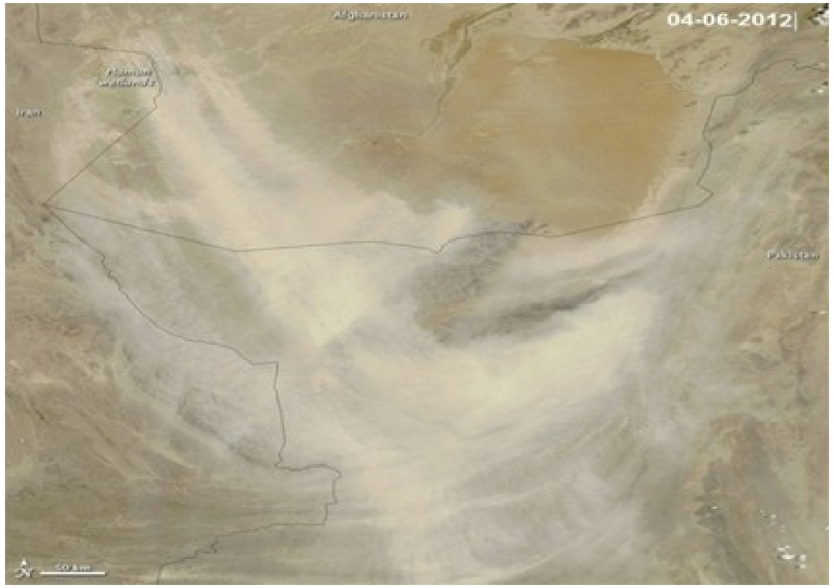
Aerosol Transport through HYSPLIT model

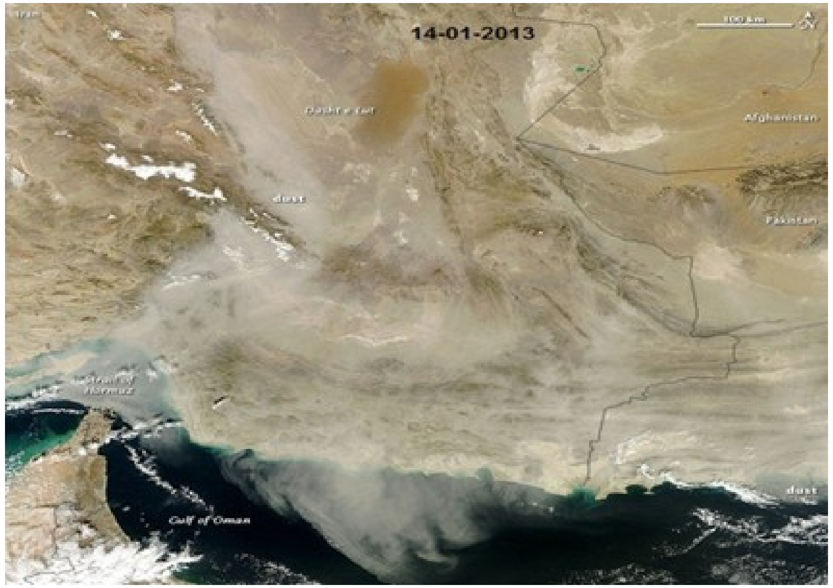




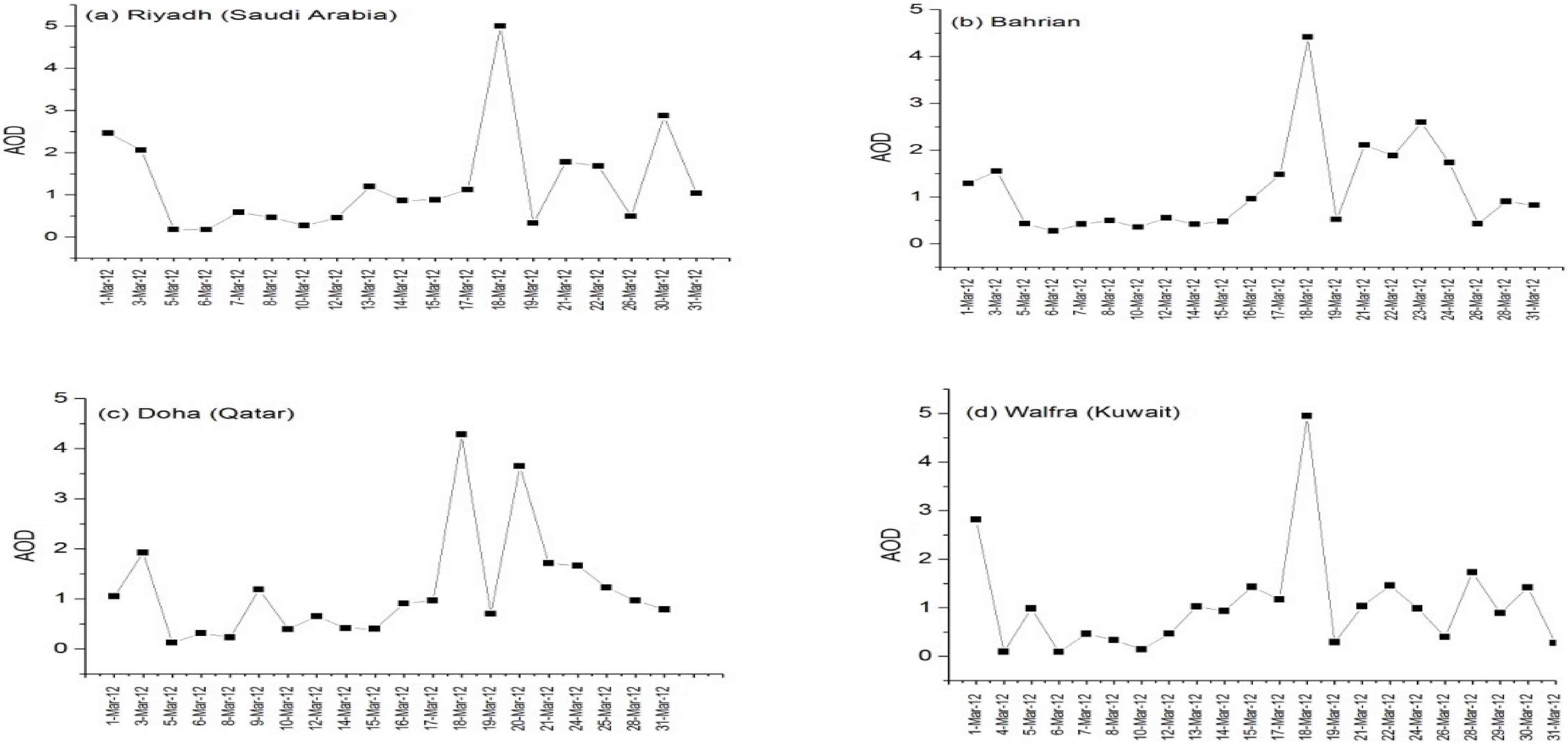
Dust detection through Satellite



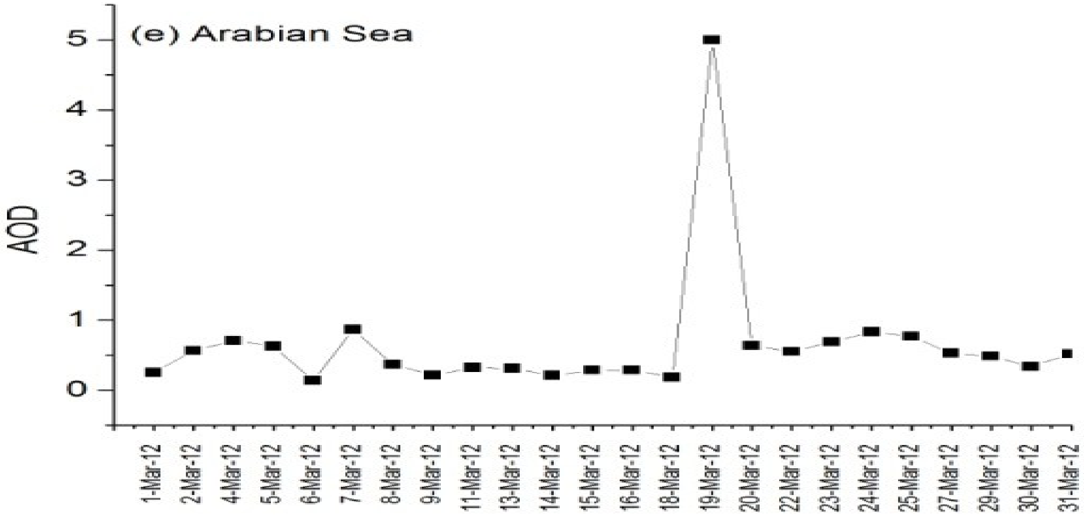


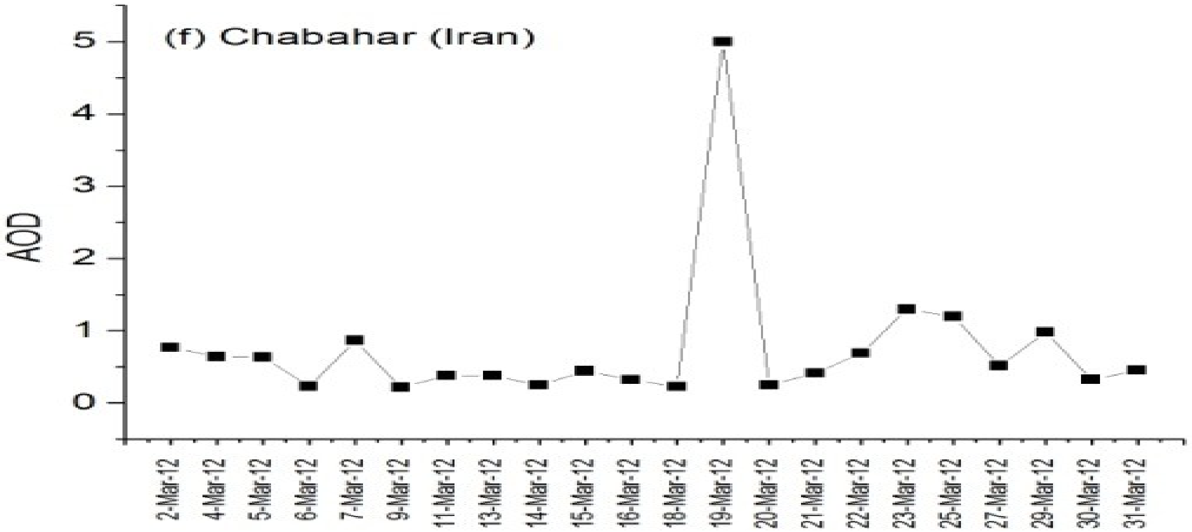


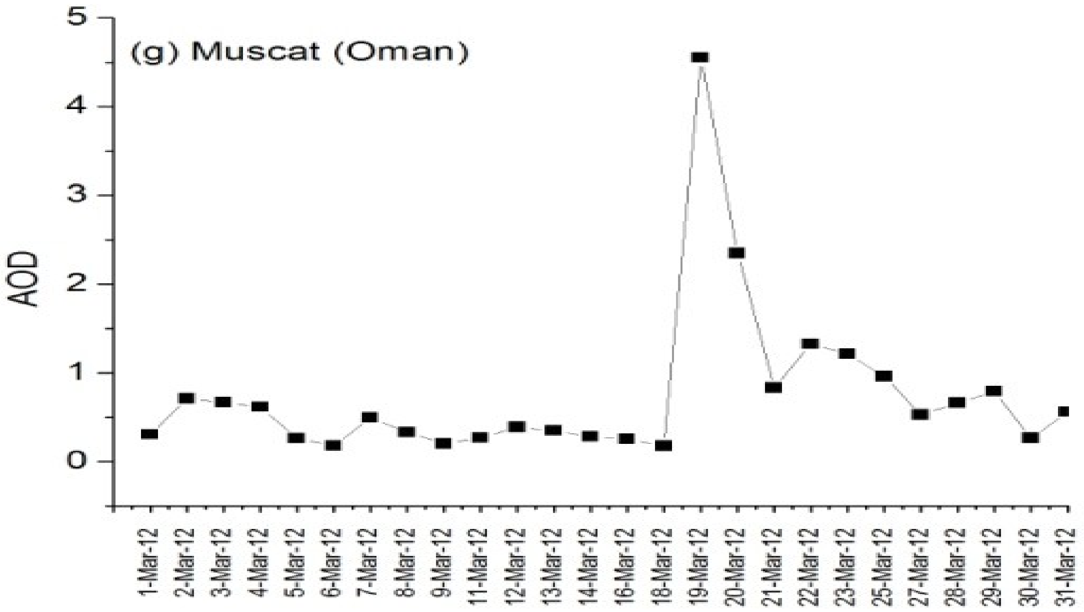
❖Results & Discussion: Aerosol Optical Depth Variations

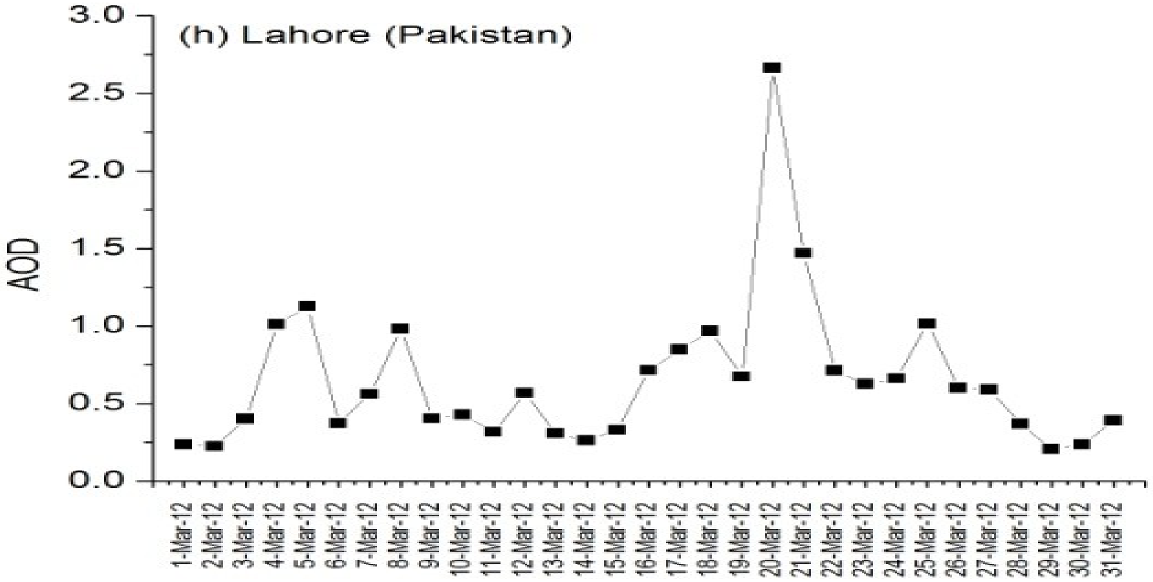


❖Results & Discussion: Aerosol Optical depth variations

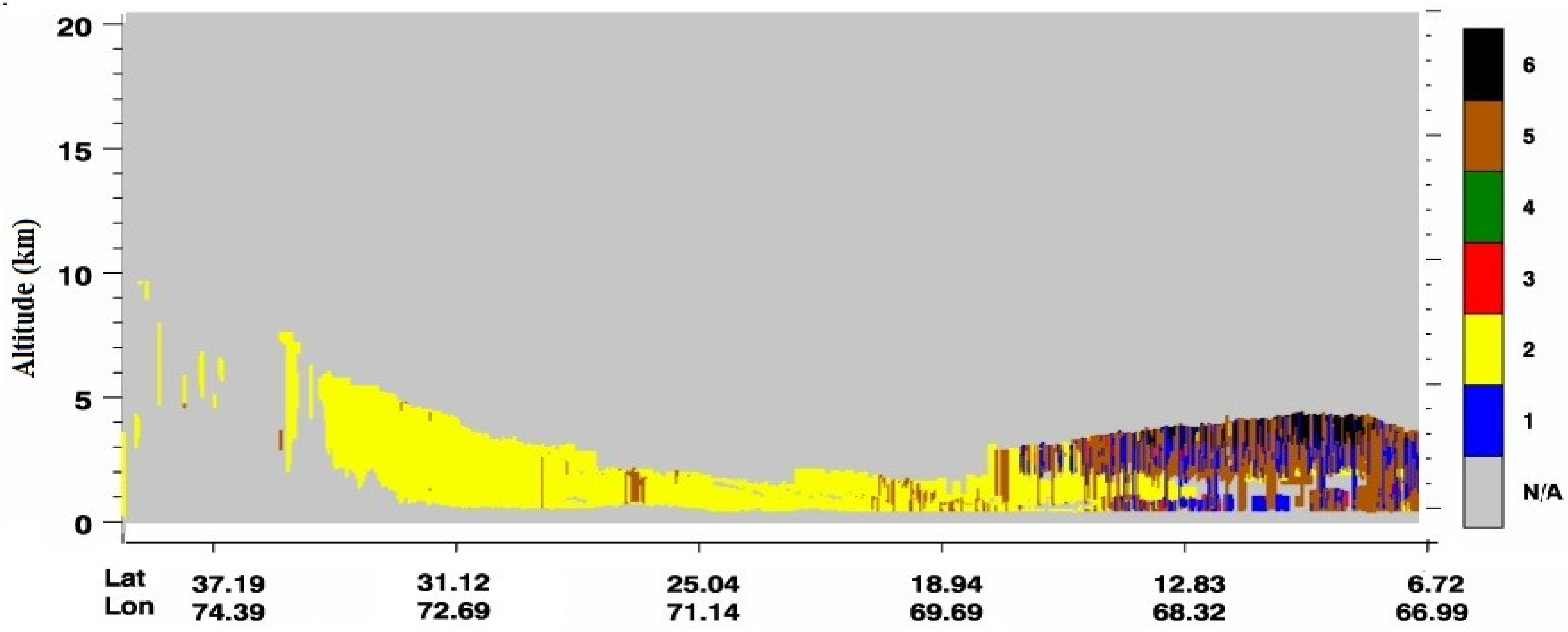






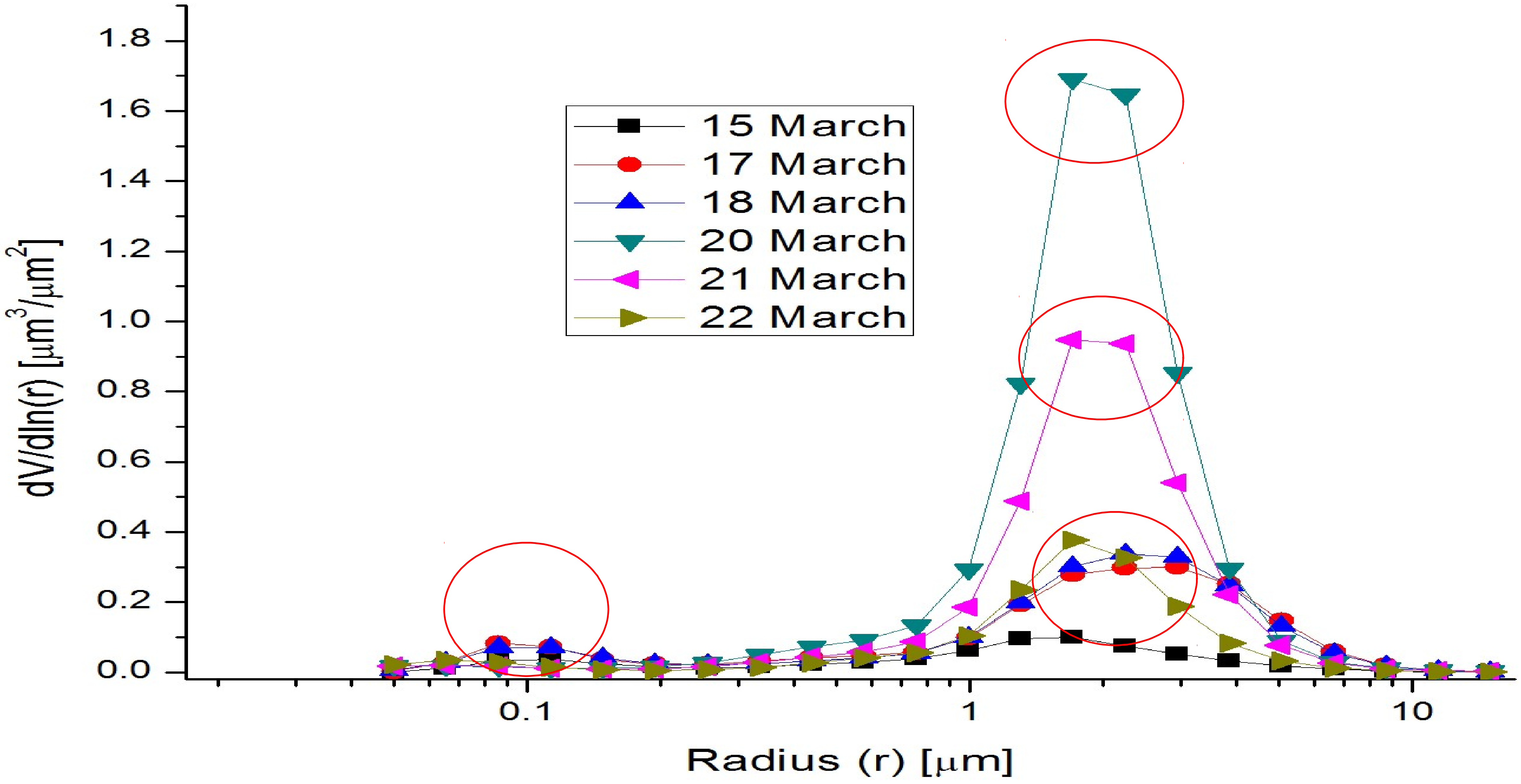


Aerosol sub-type classification

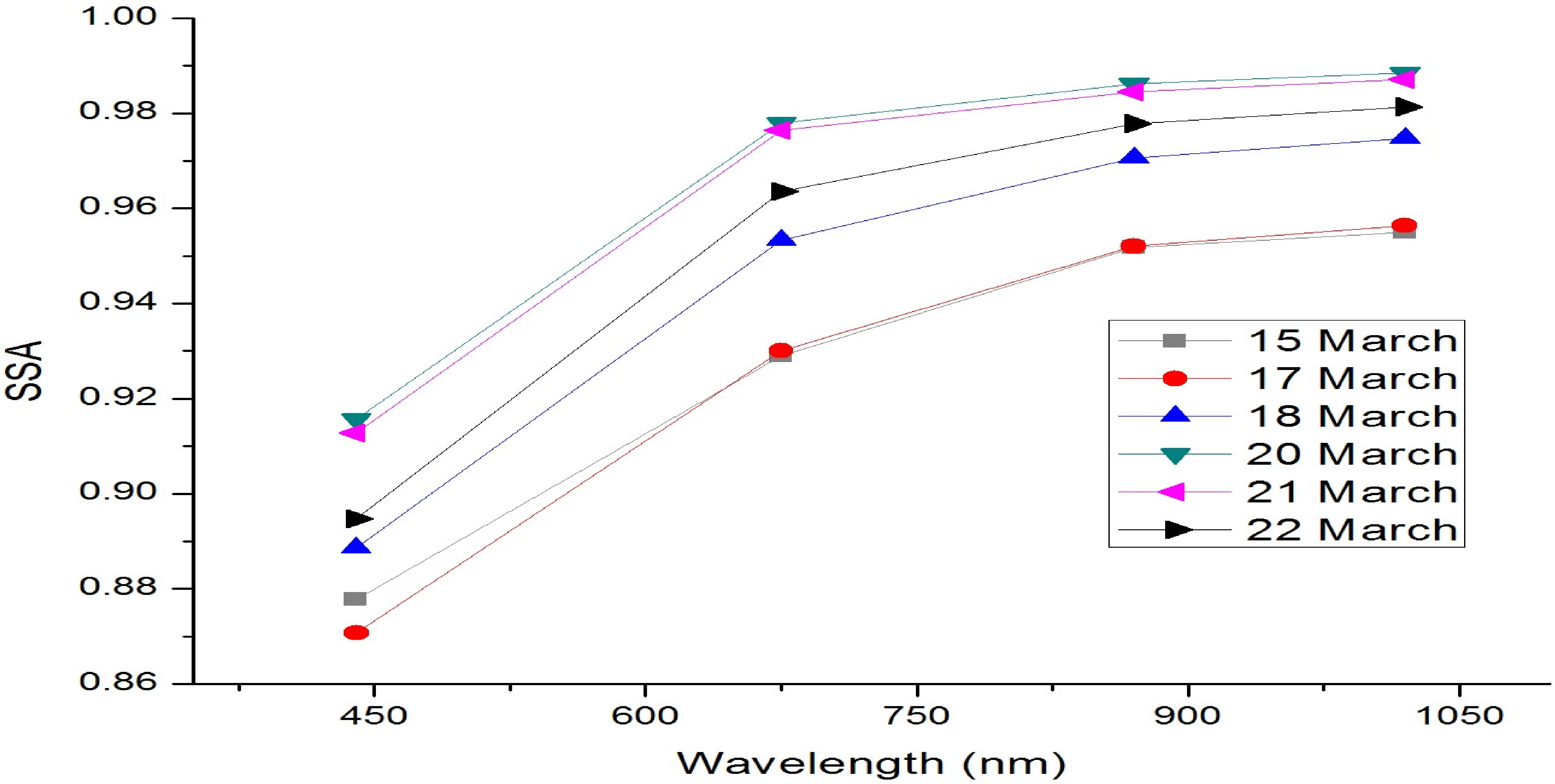


N/A = not applicable; 1= clean marine; 2 = dust; 3 = polluted continental; 4 = clean continental; 5 = polluted dust; 6 = smoke

❖Results & Discussion



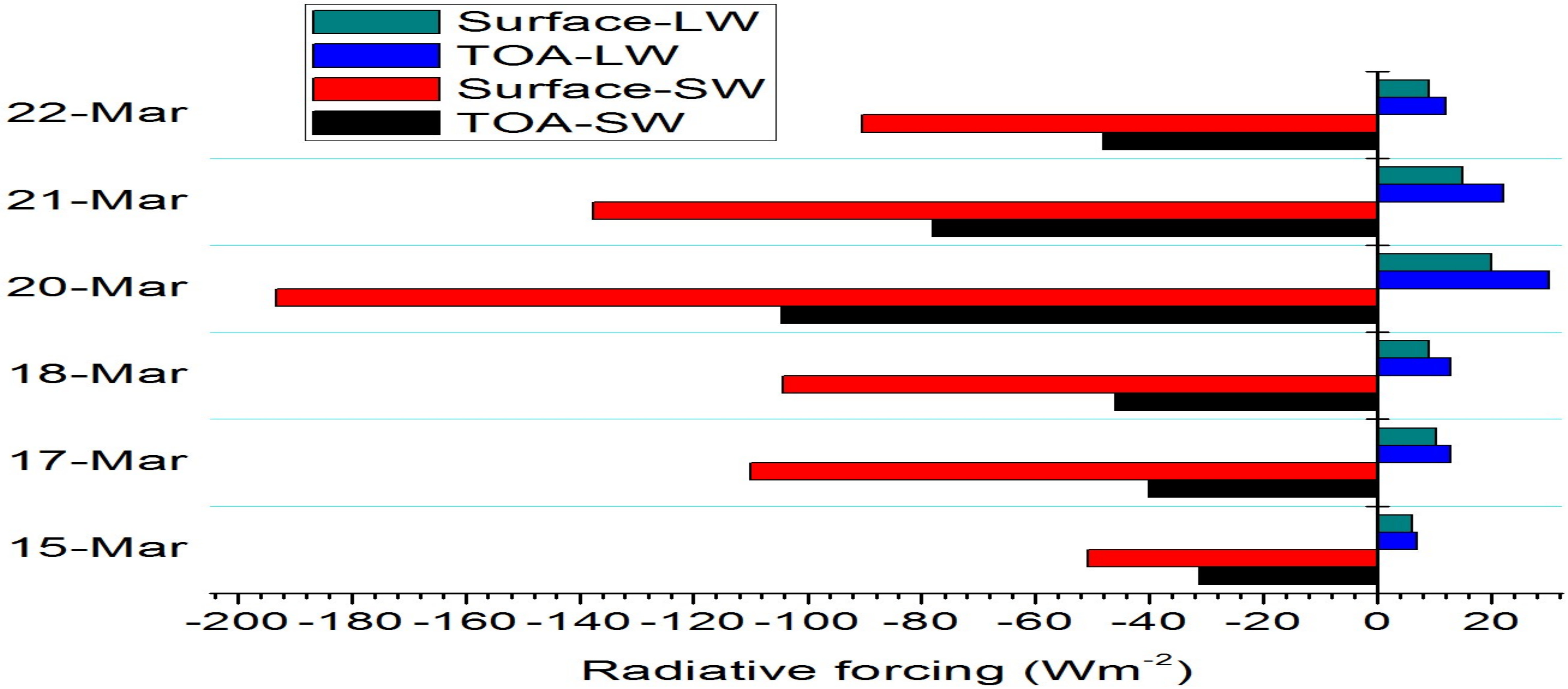
❖Results & Discussion



❖Results & Discussion

SW
TOA : −58±15 Wm^{-2}
Surface: −114±30 Wm^{-2}

LW
TOA :+12±3 Wm^{-2}
Surface:+16±5 Wm^{-2}

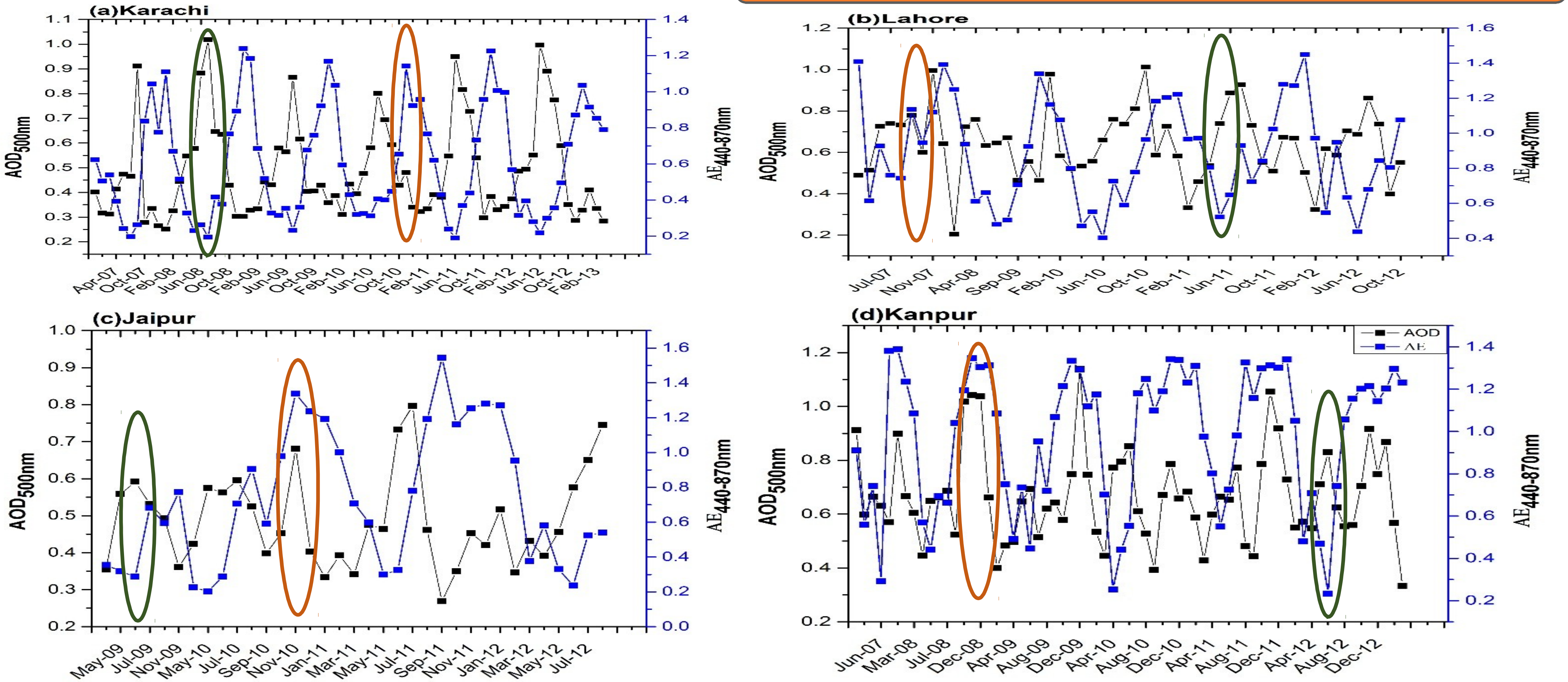


Classification of Aerosols

Monthly Averaged Variability of AOD and AE

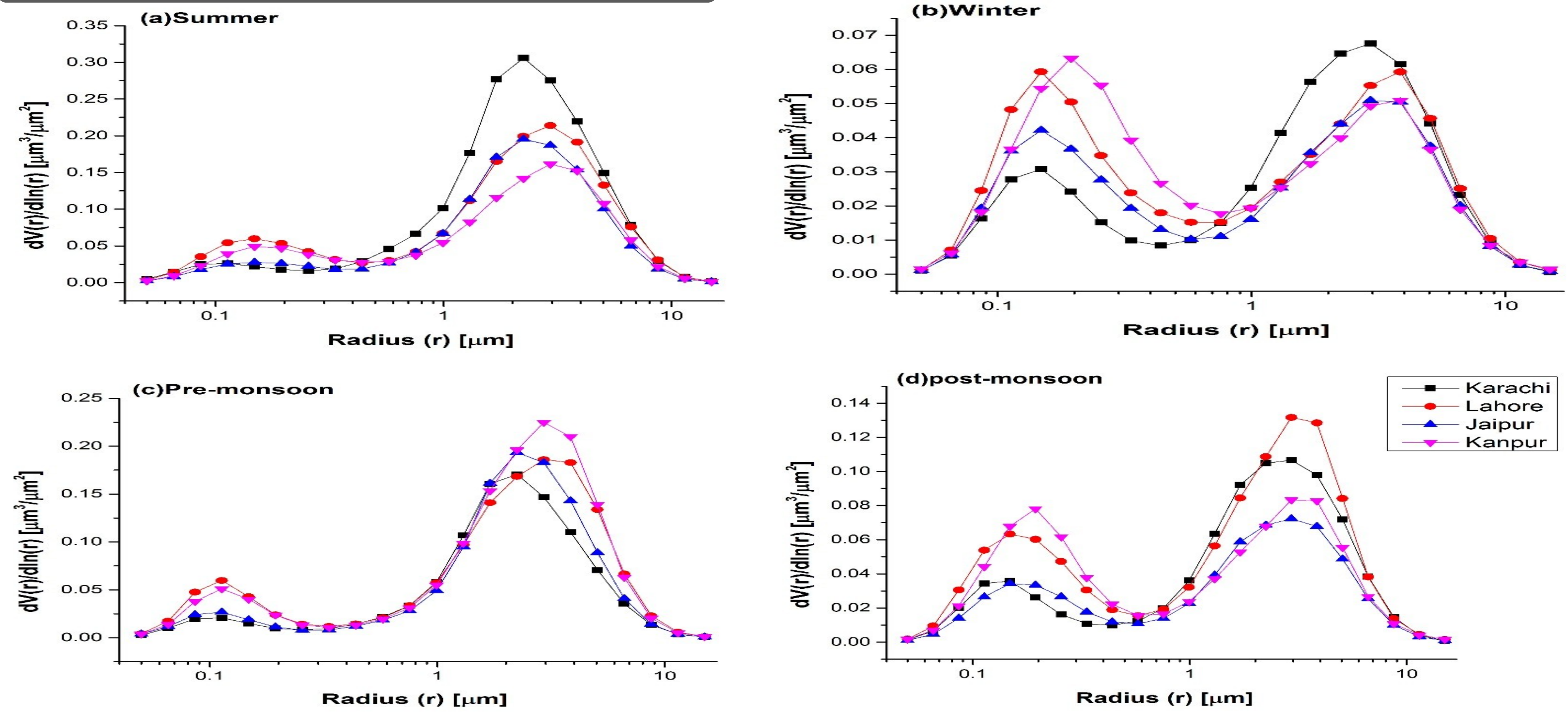
High AOD with low AE during summer and pre-monsoon months

High AOD with high AE during winter and post-monsoon



Seasonal Averaged Variability of AVSD

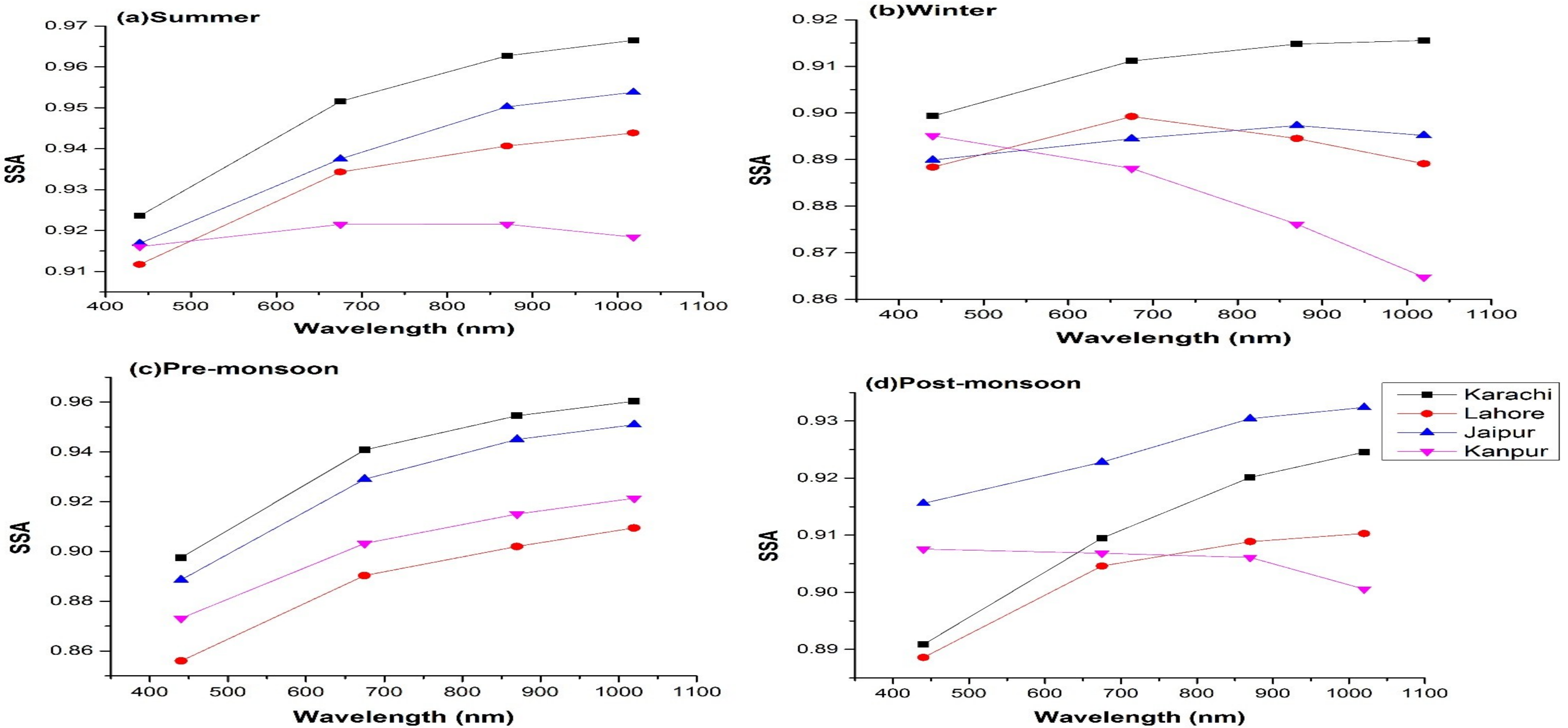
High coarse-mode peak in summer and pre-monsoon



Seasonal Averaged Variability of SSA

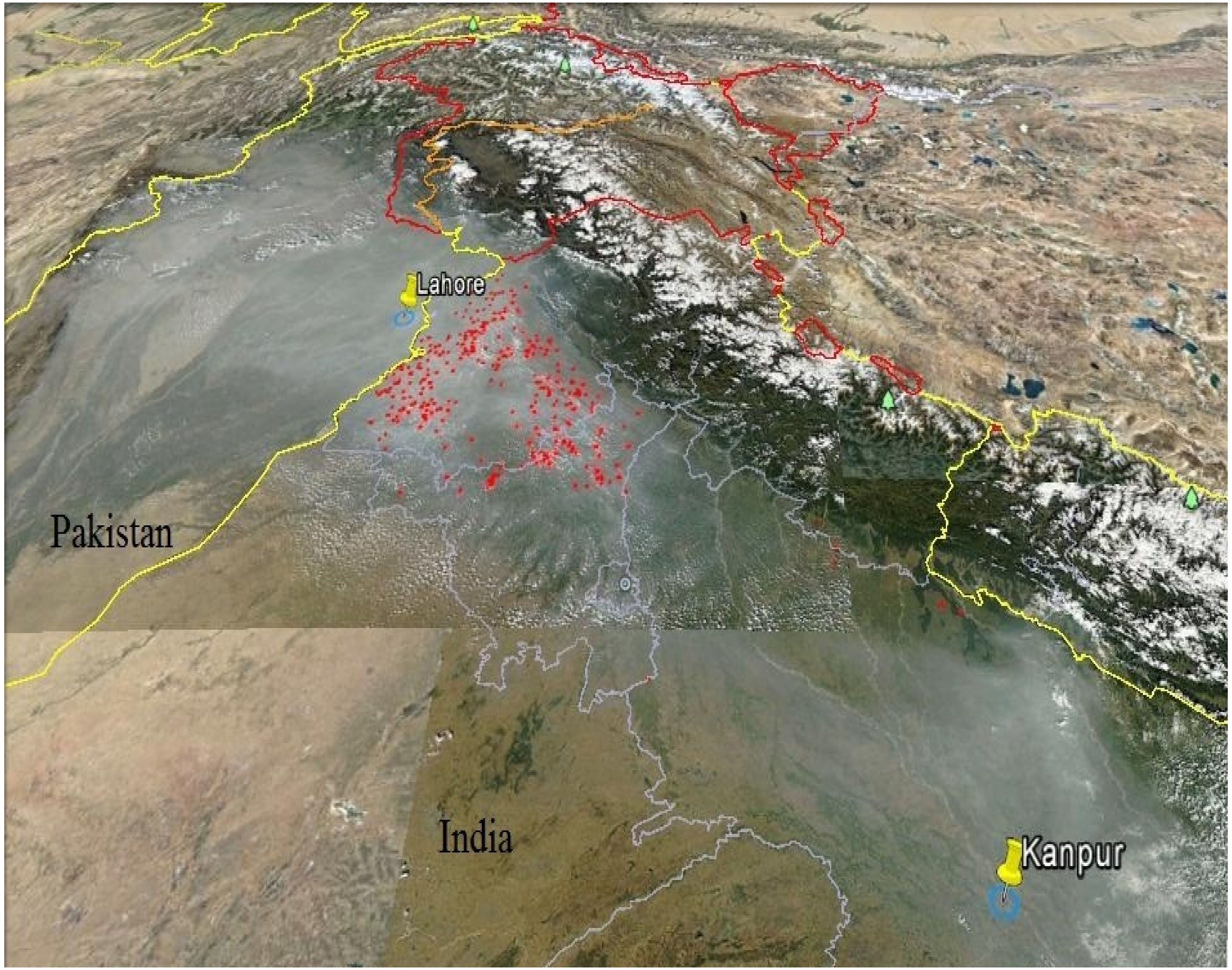
SSA increases with increasing wavelength

SSA values decreases with increasing wavelength

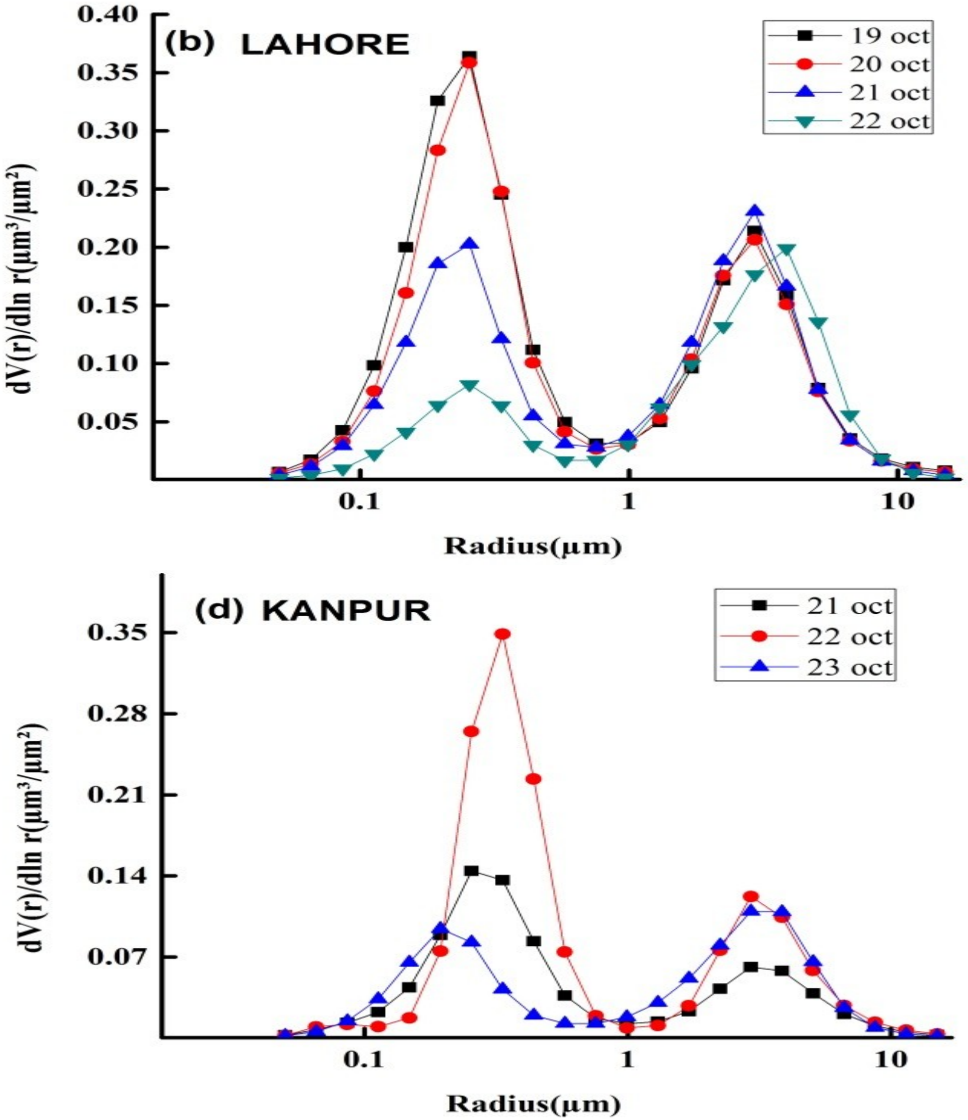


Seasonal Averaged Variability of SSA

Smoke/Haze

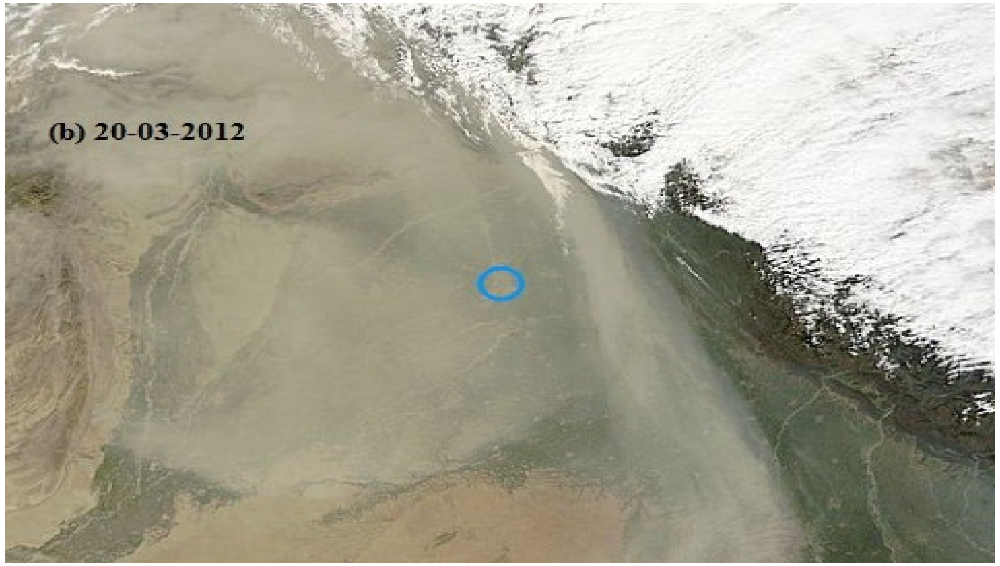


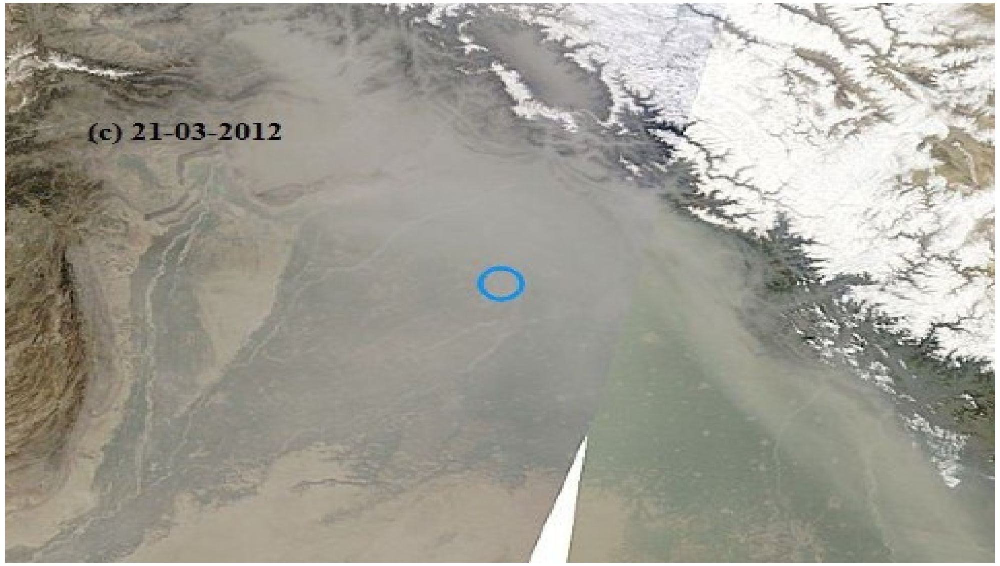
Volume size distribution



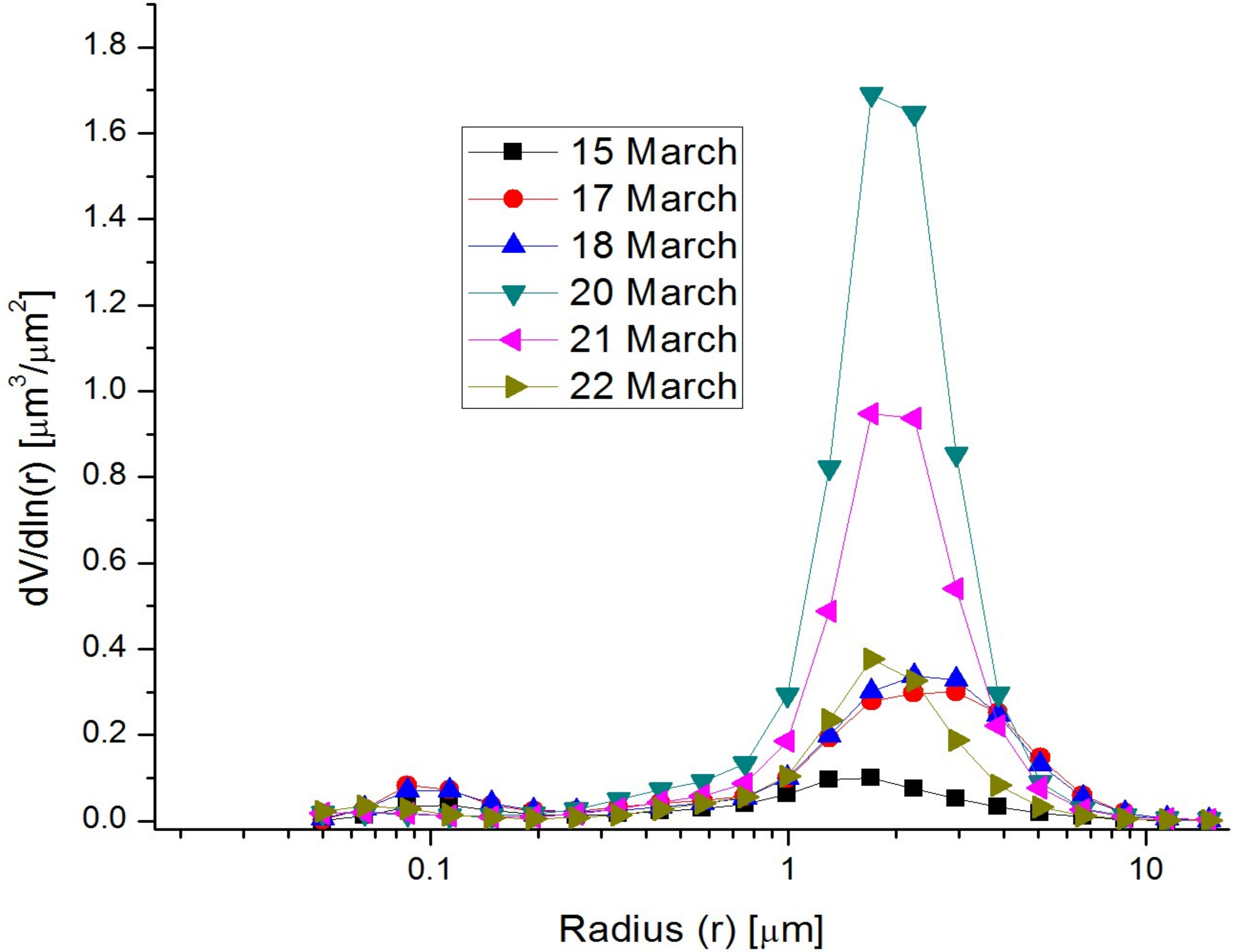
Seasonal Averaged Variability of SSA

Dust



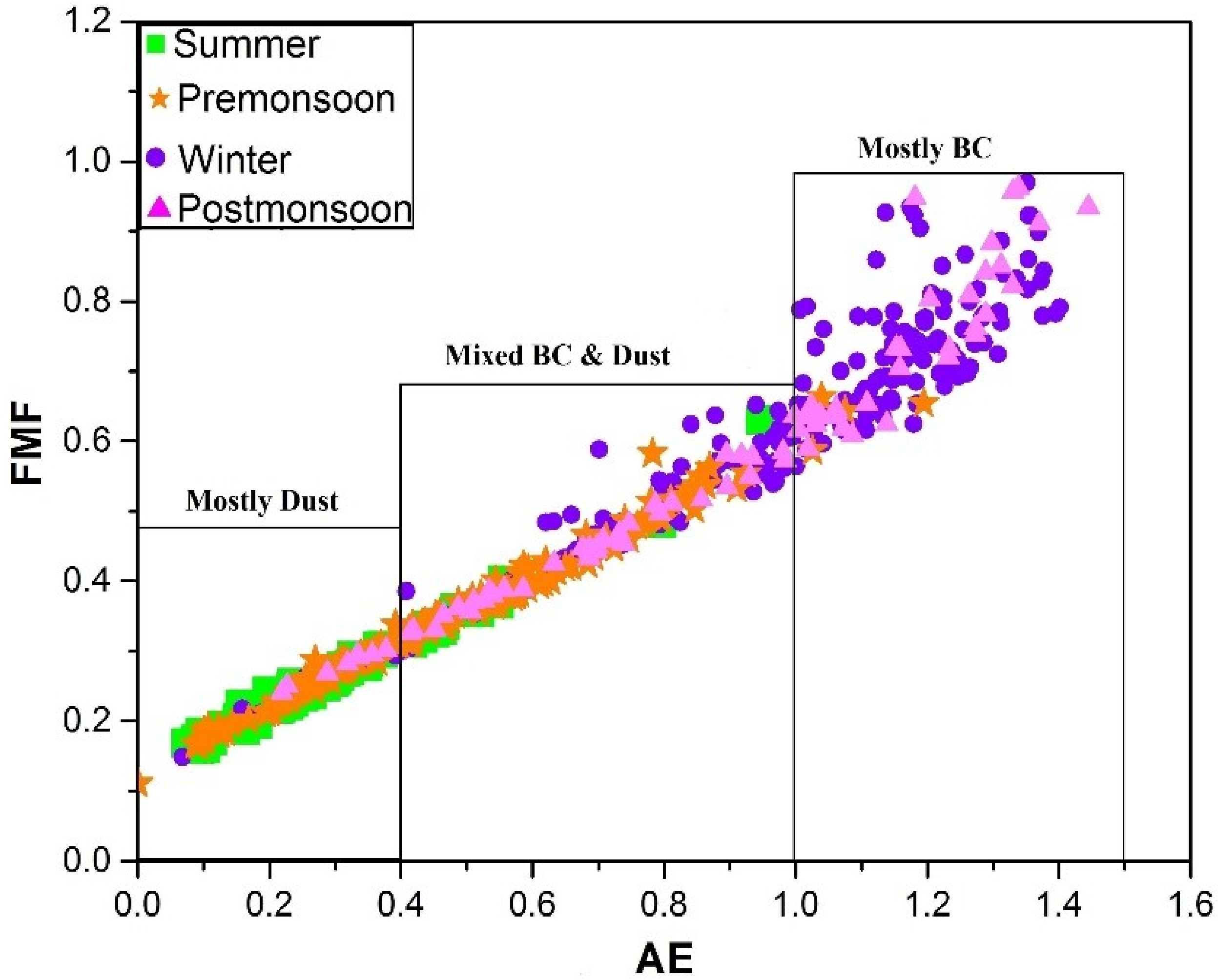


Volume size distribution



Classification of Aerosol

Relationship between FMF and AE

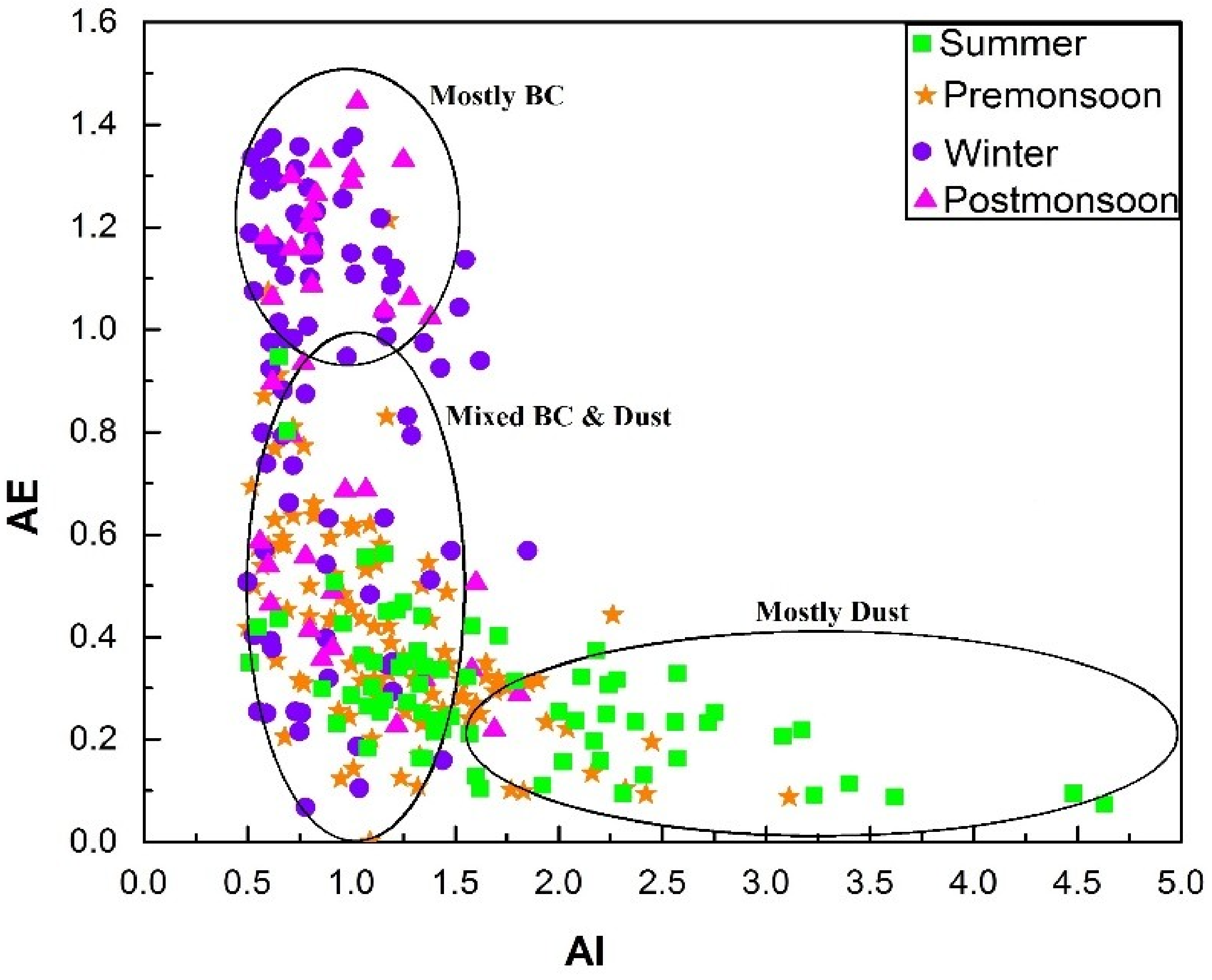


Mostly Dust ⇨ summer and premonsoon
Mostly BC ⇨ winter and postmonsoon

Aerosol types	FMF vs. AE	
Mostly Dust	0.4<FMF>0.1	0.4<AE>0.0
Mostly BC	1.0<FMF>0.7	1.5<AE>1.0
Mixed BC & Dust	0.7<FMF>0.4	1.0<AE>0.4

Classification of Aerosol

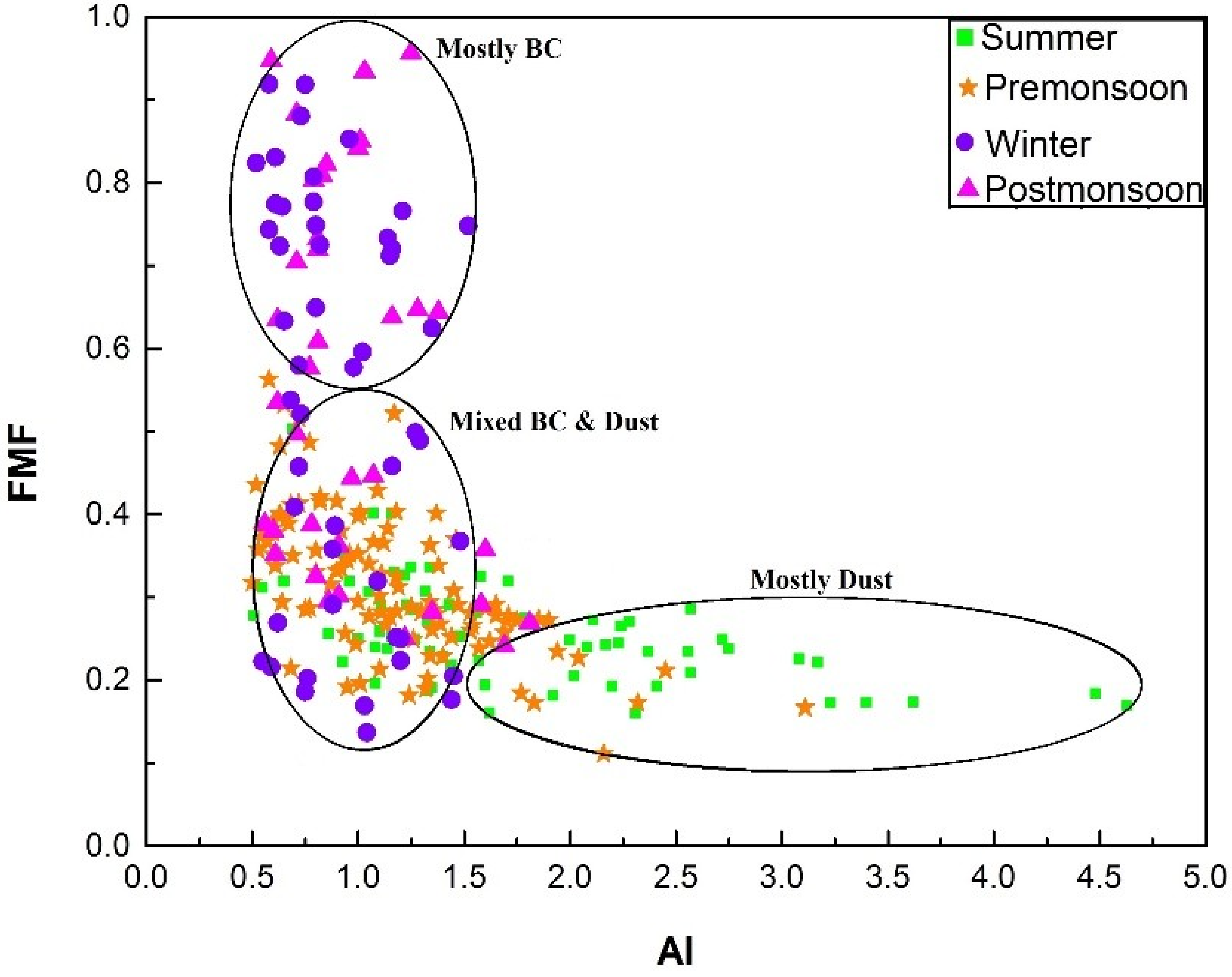
Relationship between AE and AI



Mostly Dust ⇨ summer and premonsoon
Mostly BC ⇨ winter and postmonsoon

Aerosol types	AE vs. AI	
Mostly Dust	0.4<AE>0.0	5.0<AI>1.57
Mostly BC	1.50<AE>0.92	1.52<AI>0.44
Mixed BC & Dust	1.0<AE>0.0	1.55<AI>0.5

Relationship between FMF and AI

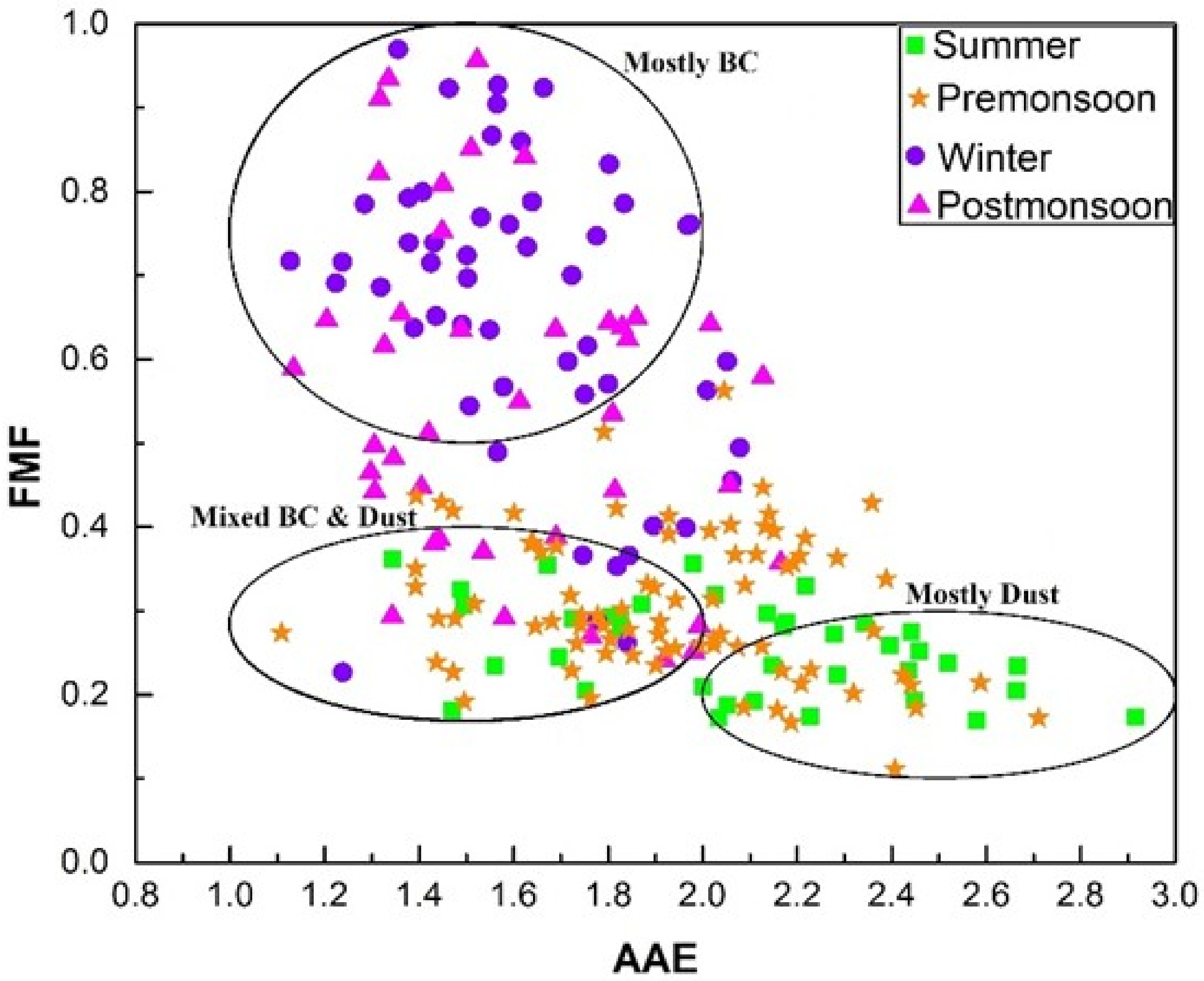


Mostly Dust ⇨ summer and premonsoon
Mostly BC ⇨ winter and postmonsoon

Aerosol types	FMF vs. AI	
Mostly Dust	0.3 <FMF>0.1	4.5<AI> 1.50
Mostly BC	1.0<FMF>0.57	1.55<AI>0.4
Mixed BC & Dust	0.55<FMF>0.1	1.55<AI>0.5

Classification of Aerosol

Relationship between FMF and AAE

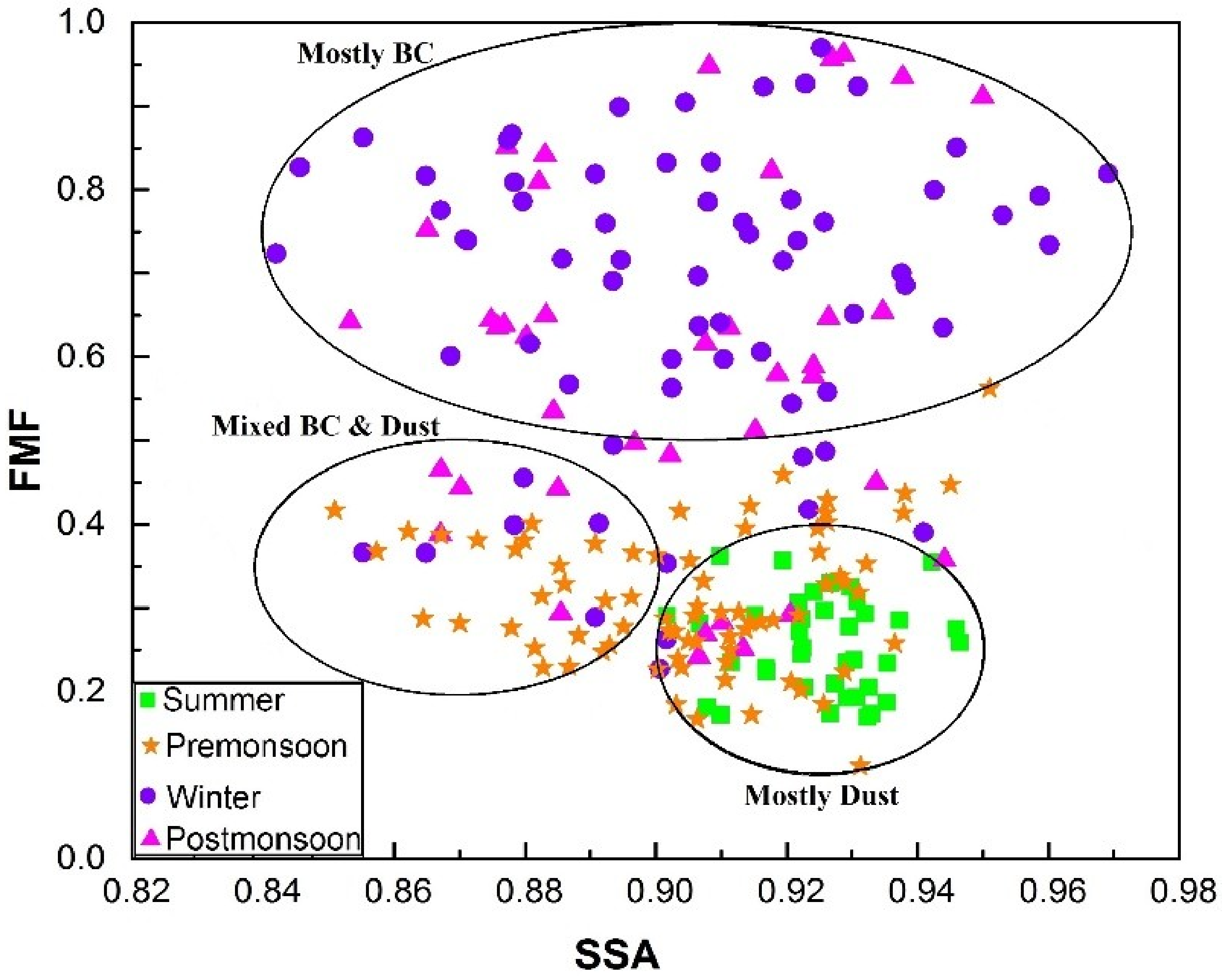


Mostly Dust ⇨ summer and premonsoon
Mostly BC ⇨ winter and postmonsoon

Aerosol types	FMF vs. AAE	
Mostly Dust	0.3<FMF>0.1	3.0<AAE>2.0
Mostly BC	1.0<FMF>0.5	2.0<AAE>1.0
Mixed BC & Dust	0.4<FMF>0.1	2.0<AAE>1.0

Classification of Aerosol

Relationship between FMF and SSA



Mostly Dust ⇨ summer and premonsoon
Mostly BC ⇨ winter and postmonsoon

Aerosol types	FMF vs. SSA	
Mostly Dust	0.4<FMF>0.1	0.95<SSA>0.90
Mostly BC	1.0<FMF>0.5	0.91<SSA>0.84
Mixed BC & Dust	0.4<FMF>0.2	0.90<SSA>0.84

با تشکر از
توجه شما