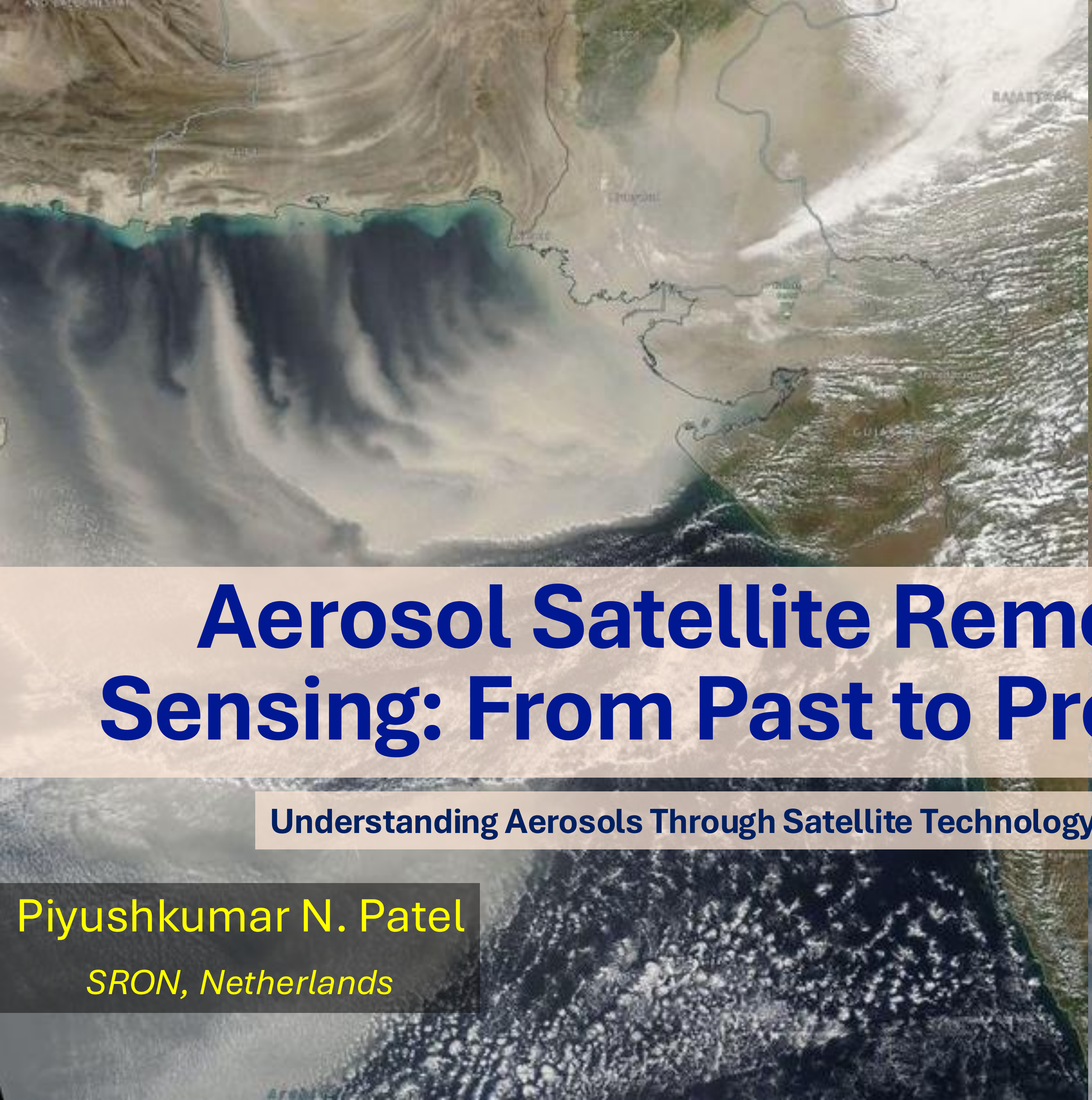
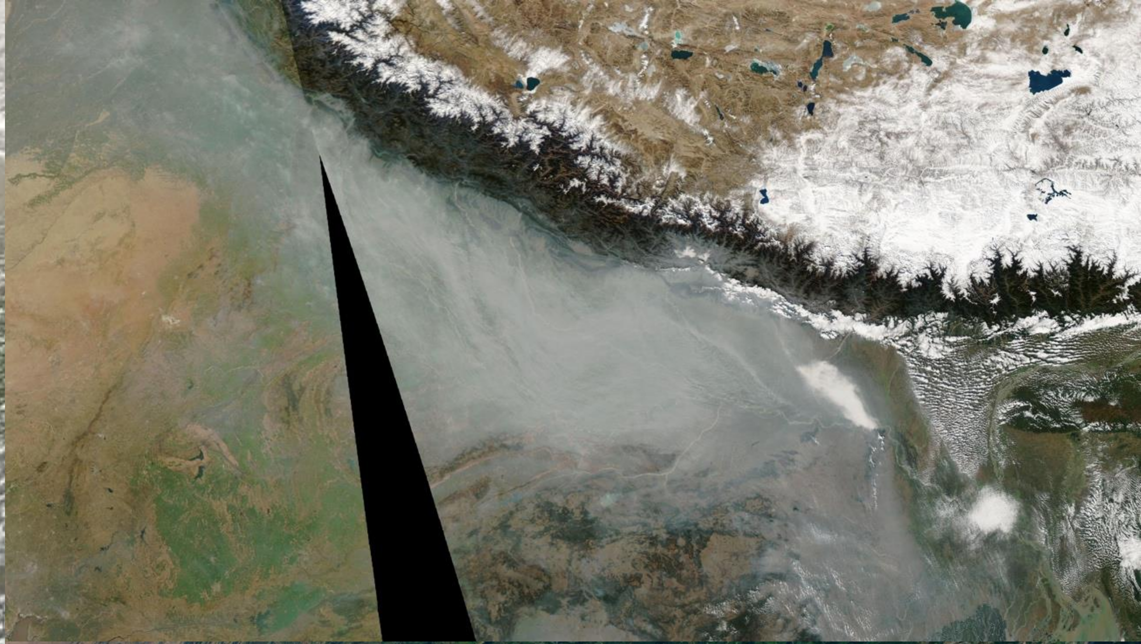
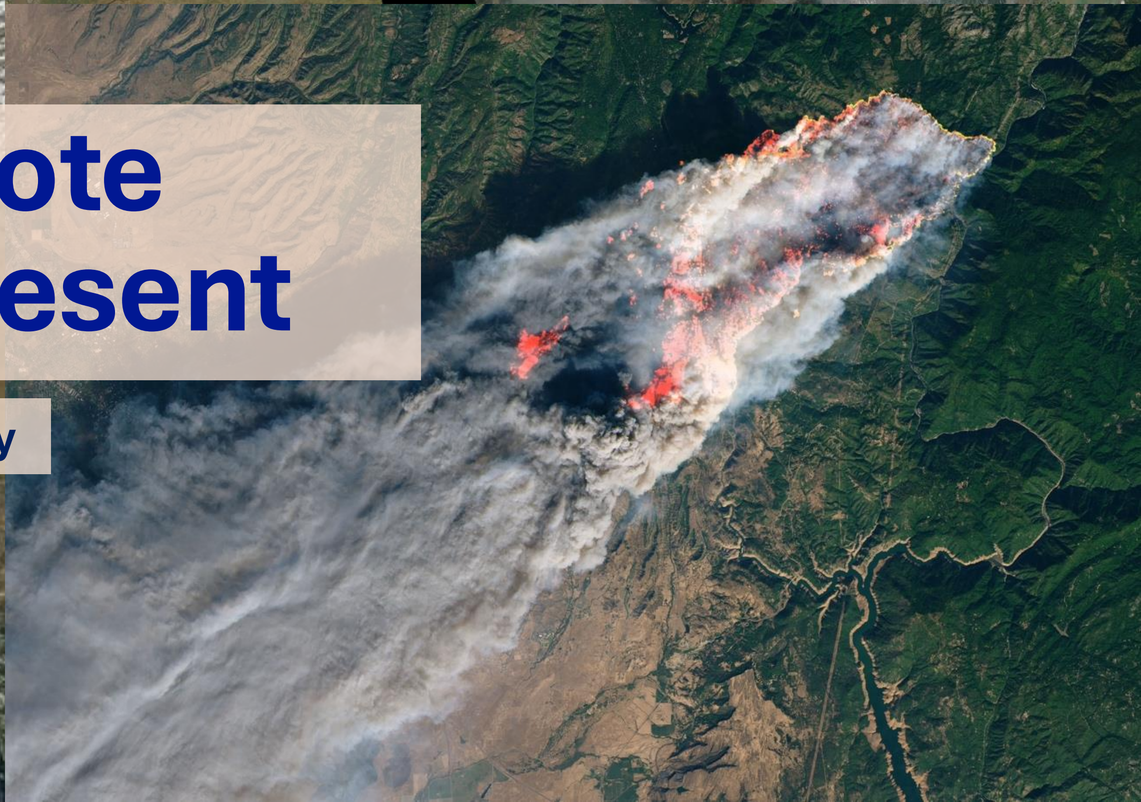






Aerosol Satellite Remote Sensing: From Past to Present

Understanding Aerosols Through Satellite Technology

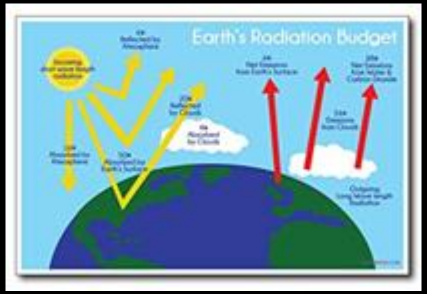
Piyushkumar N. Patel

SRON, Netherlands

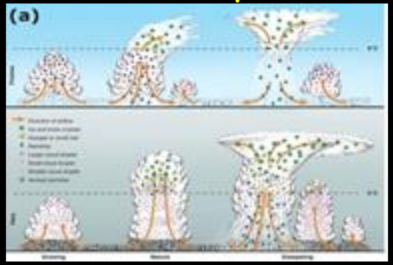
What is Atmospheric Aerosol ???

- Simply a form of air pollutant
- Aerosol includes both the particles and the suspending gas in the atmosphere with size ranges of few nanometres to more than 100 μm

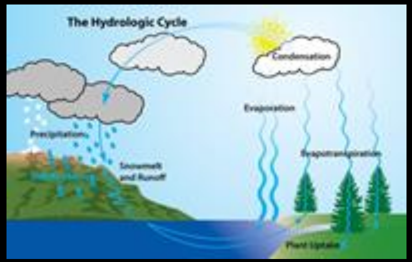
Radiation Budget



Cloud Properties



Hydrological Cycle

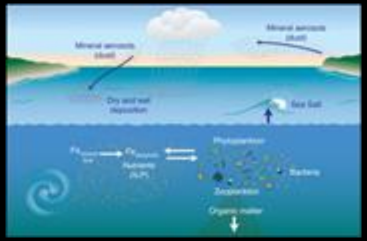


Atmospheric

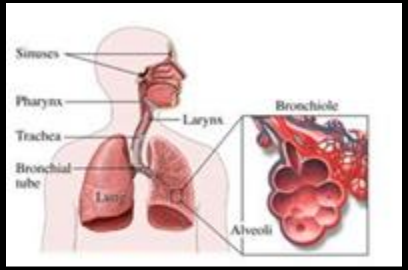
Aerosols

Visibility

Marine Environment



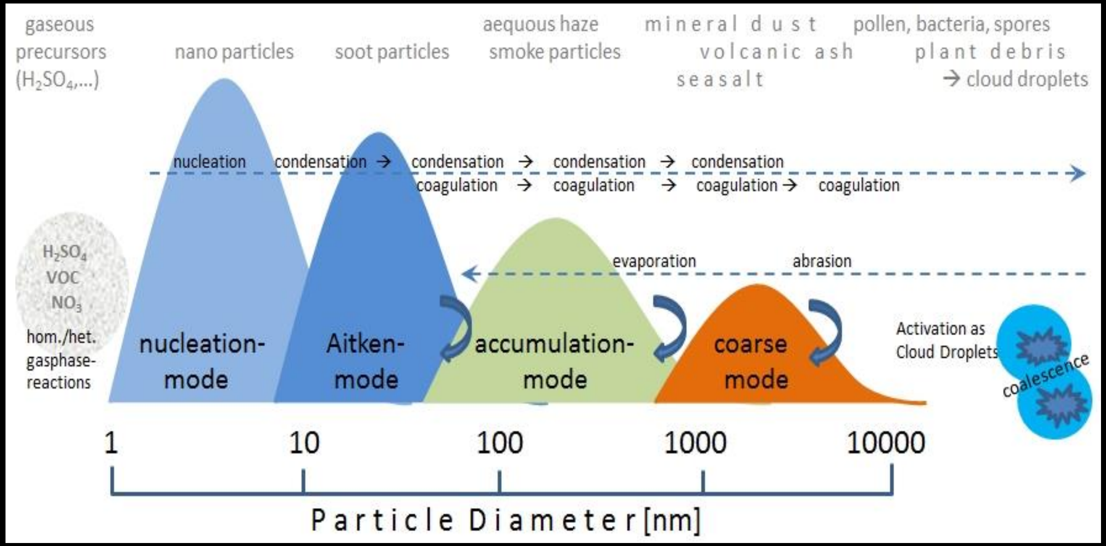
Health



Global Aerosol Budget: 70% natural + 30% anthropogenic

Aerosol Types

Aerosol Size



❖ **Primary Aerosols**

(formed directly as particles)

Industrial aerosols

Biomass Burning

Soot

❖ **Secondary Aerosols**

(formed in the atmosphere from chemical reactions)

Sulfates from industrial SO_2

Organic matter from biogenic

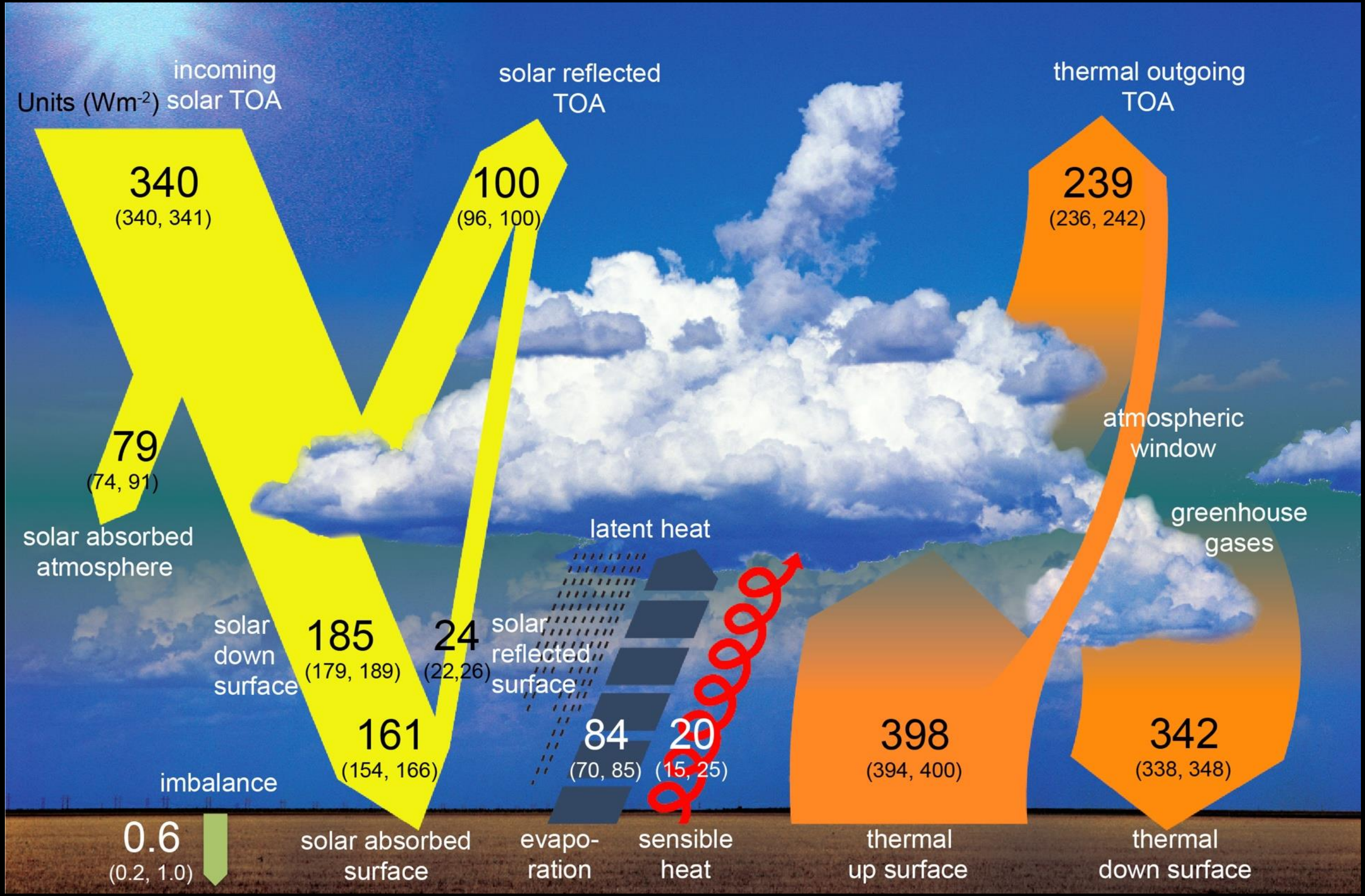
Nitrates from NO_x

Emission Sources

Natural Aerosols

Anthropogenic Aerosols

Earth's Radiation Budget & Radiative Forcing



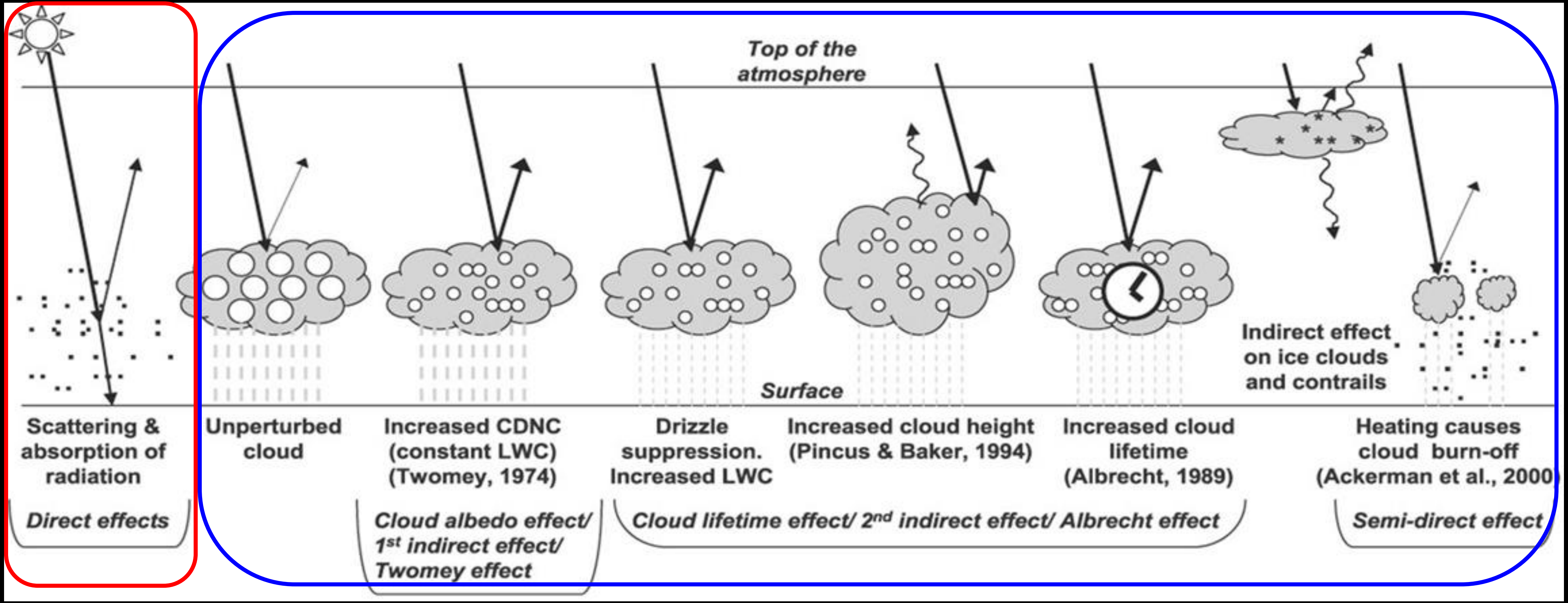
Schematic diagram of the global mean energy balance of the Earth. Numbers state magnitudes of the individual energy fluxes in W m-2, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (source: Wild et al. 2013)

Impacts of aerosols

Two Major Impacts

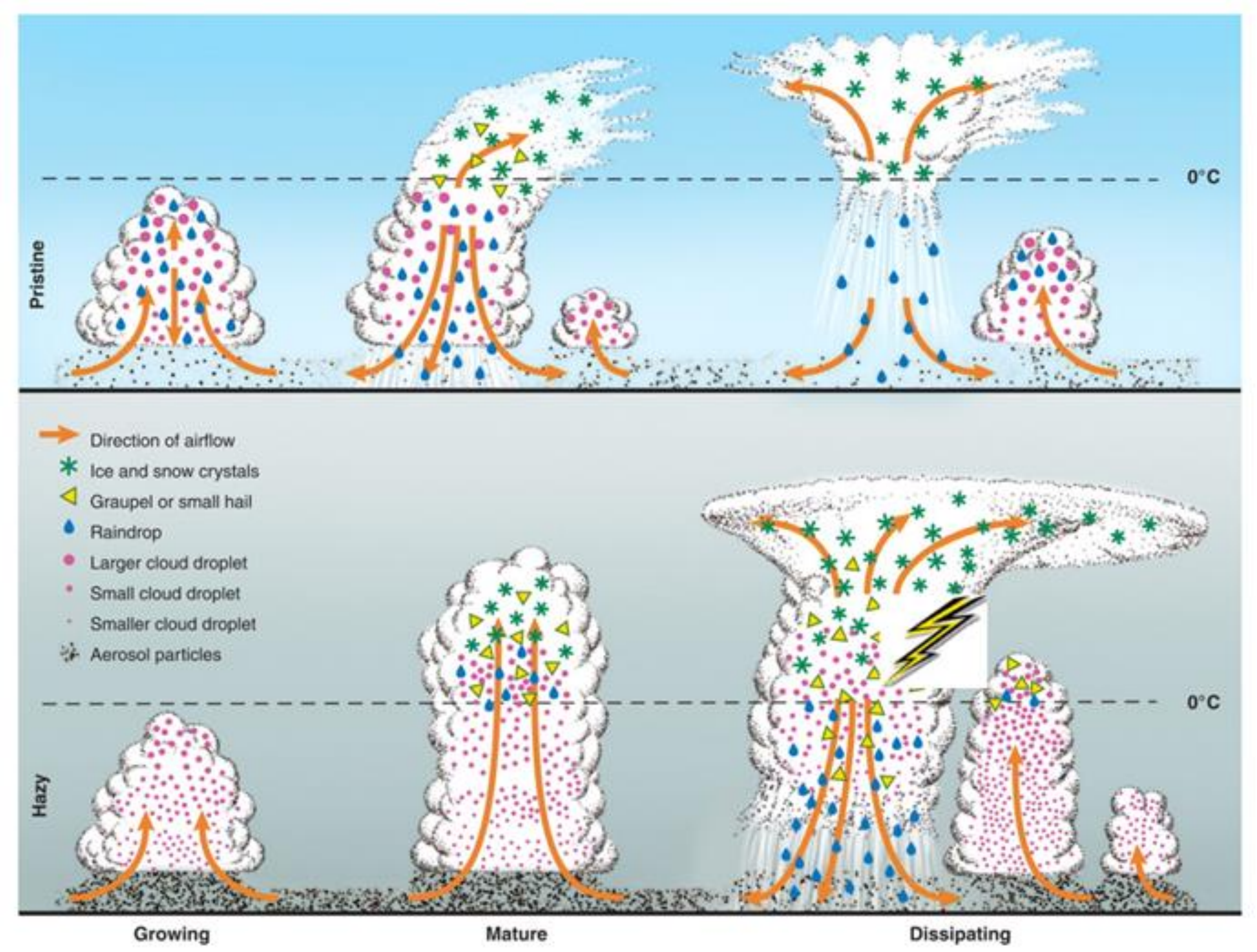
(1) Direct effect or aerosol-radiation interactions

(2) Indirect effect or aerosol-cloud interactions



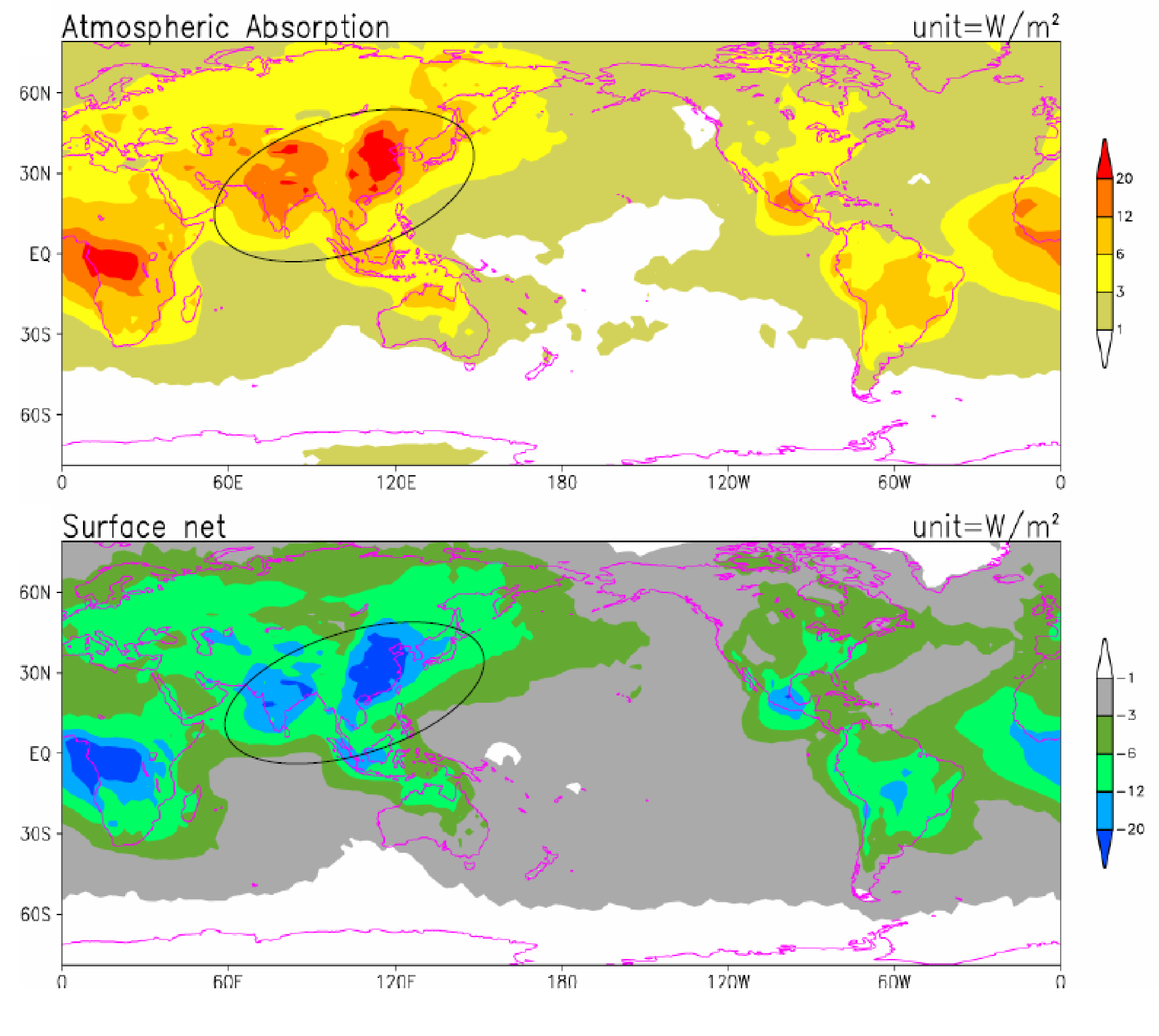
Impacts of aerosols

Indirect effect of the 3rd kind: Delayed warm rain, and prolonged cloud life time by aerosols in a monsoon (moisture-rich) environment may invigorate deep convection)



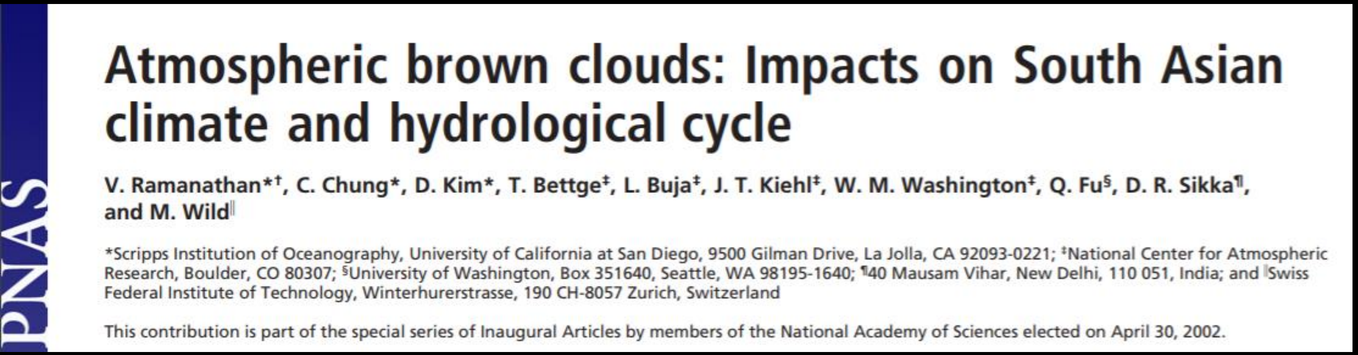
(Rosenfeld et al., 2008)

Aerosol induced atmospheric warming and surface cooling



Integration of MODIS/CERES/ISCCP/TOMS; Ace-Asia; INDOEX; AERONET/ABC/GEBA/GOCART/MACR

Chung, Ramanathan, Kim, Podgorny, 2005



Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle

V. Ramanathan*†, C. Chung*, D. Kim*, T. Bettge‡, L. Buja‡, J. T. Kiehl‡, W. M. Washington‡, Q. Fu§, D. R. Sikka¶, and M. Wild‖

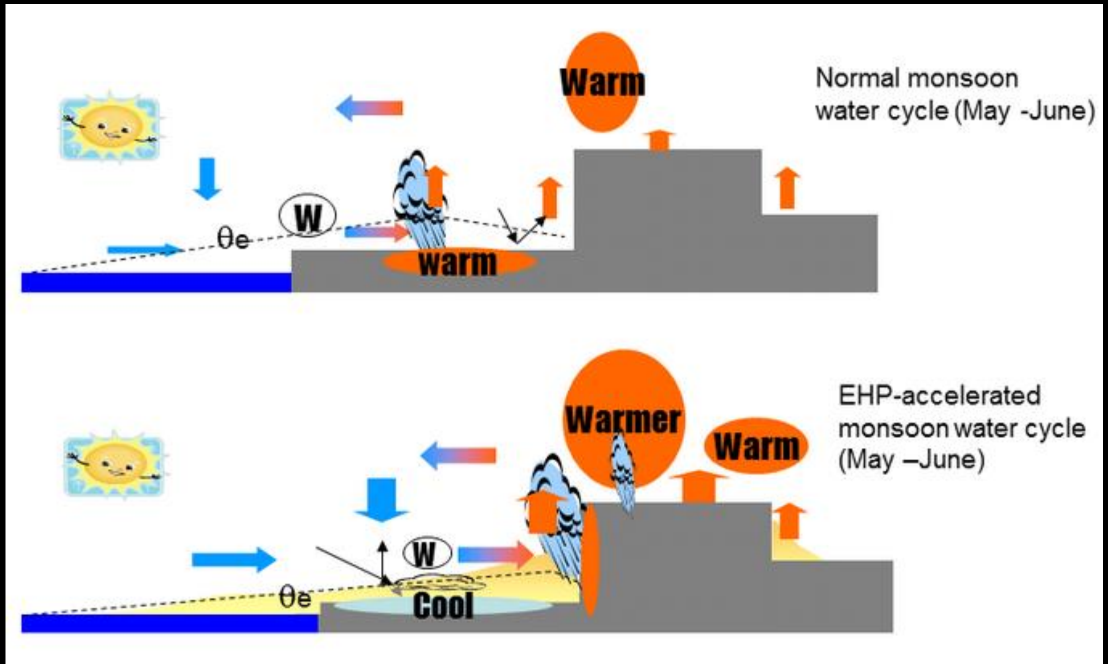
*Scripps Institution of Oceanography, University of California at San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0221; ‡National Center for Atmospheric Research, Boulder, CO 80307; §University of Washington, Box 351640, Seattle, WA 98195-1640; ¶40 Mausam Vihar, New Delhi, 110 051, India; and ‖Swiss Federal Institute of Technology, Winterhurerstrasse, 190 CH-8057 Zurich, Switzerland

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected on April 30, 2002.

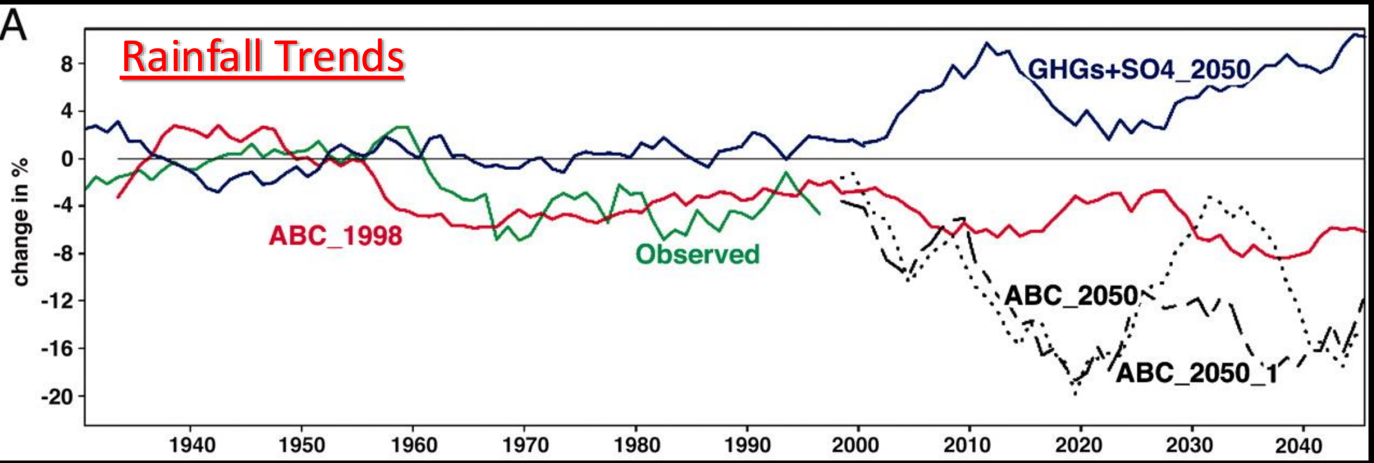
The Elevated Heat Pump (EHP) Hypothesis

Lau et al., 2006. Lau & Kim 2006

Weakening of the South Asian Monsoon as a response to absorbing aerosols (e.g. black carbon)



EHP postulates: a) an advance of the rainy season in northern India/Napal region in May-June b) In July-August, the increased convection spreads from the foothills of the HImalayas to central India, resulting in an intensification of the Indian monsoon.



nature geoscience
ARTICLES
PUBLISHED ONLINE: 16 MARCH 2014 | DOI: 10.1038/NGEO2107

Short-term modulation of Indian summer monsoon rainfall by West Asian dust

V. Vinoj[1,2], Philip J. Rasch[1*], Hailong Wang[1], Jin-Ho Yoon[1], Po-Lun Ma[1], Kiranmayi Landu[1,2] and Balwinder Singh[1]

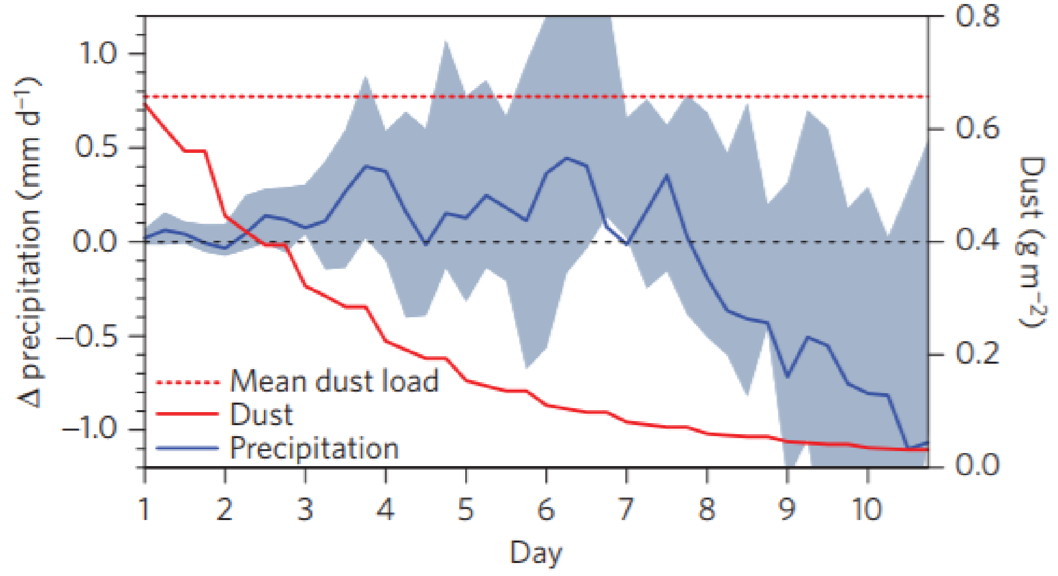


Figure 5 | The short-time response of precipitation to dust forcing as estimated from the composite of two 19-member sets of ten-day simulations (the DPE). The blue line corresponds to changes in

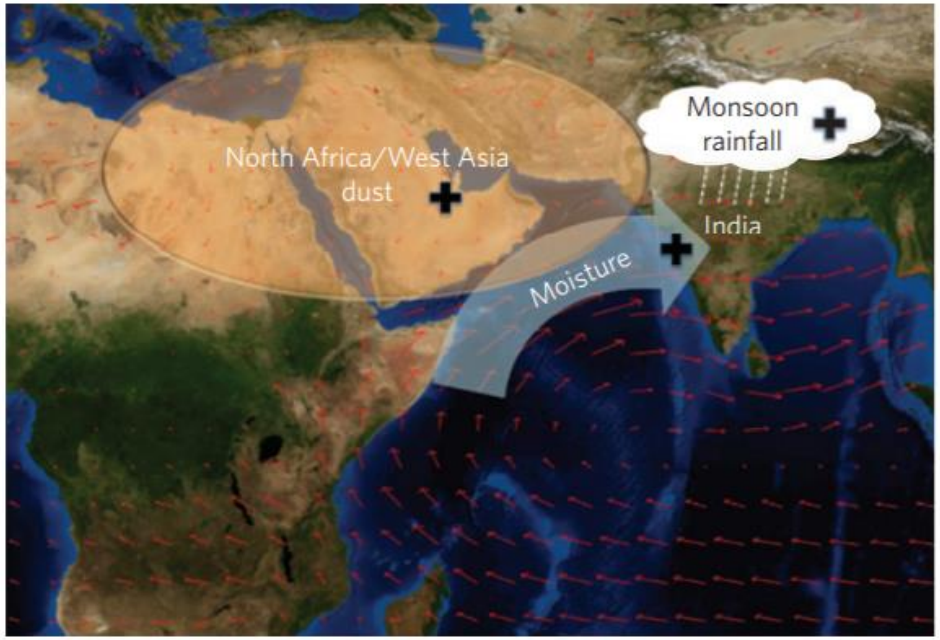
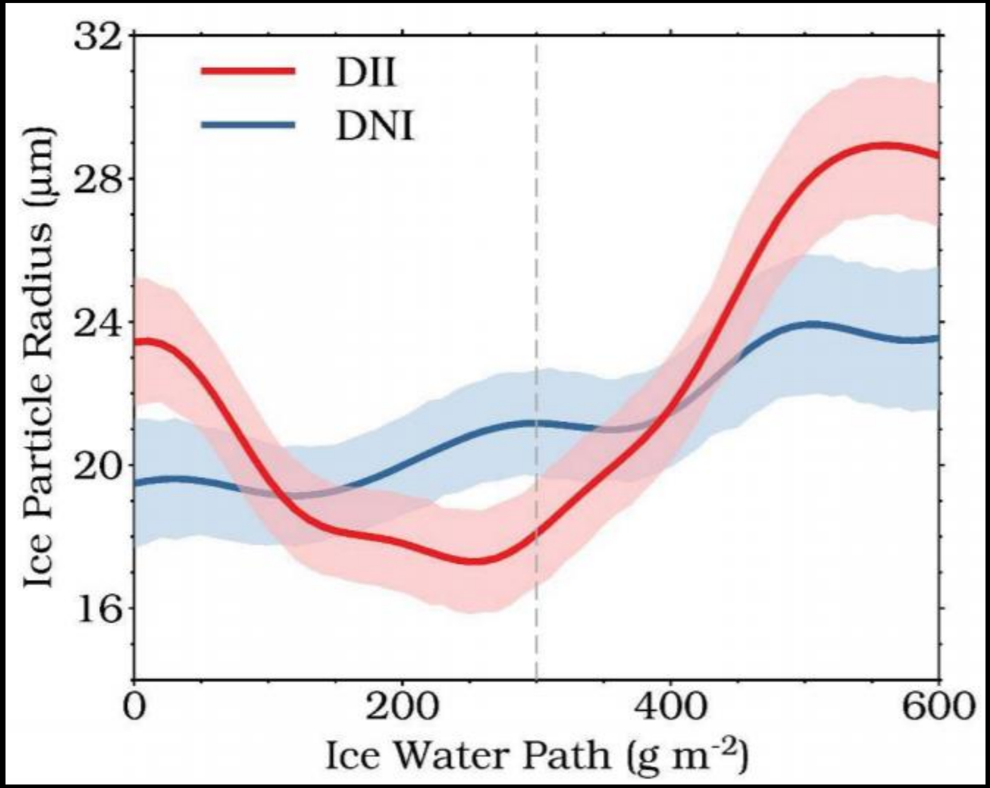


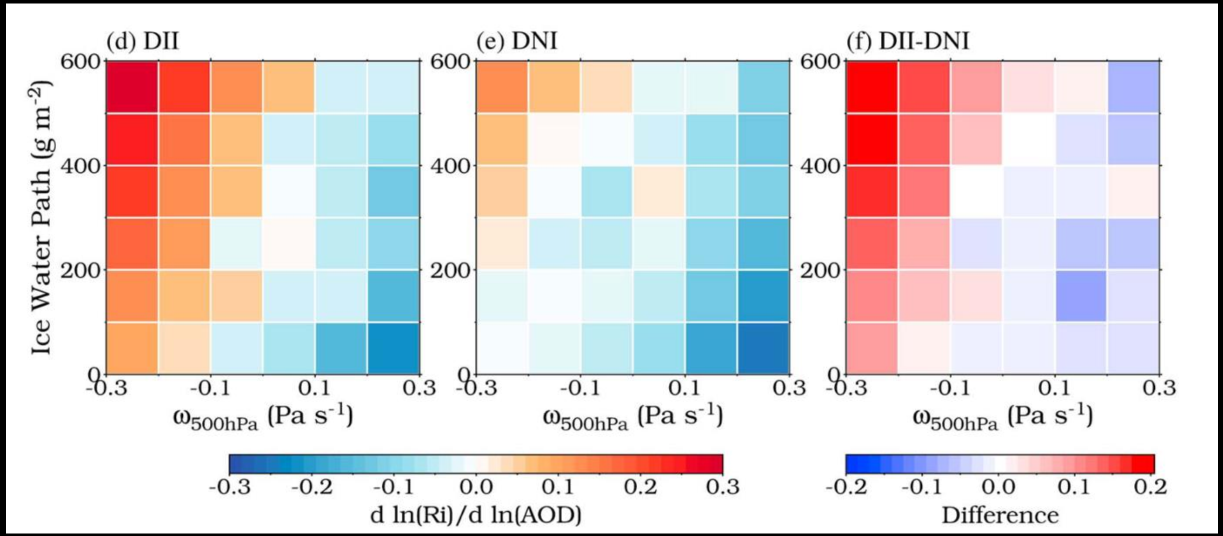
Figure 6 | Schematic representation of the circulation and monsoon rainfall response to dust aerosols over North Africa and West Asia suggested here. The true-colour image of the Earth (a product of NASA's

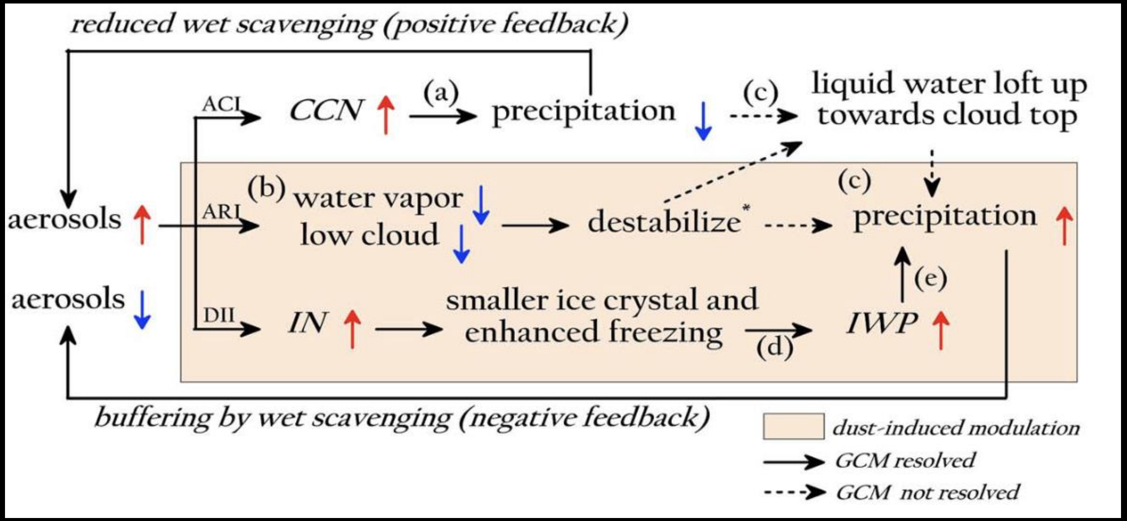
Desert dust modifying ice clouds and affecting monsoon rainfall?

Elevated dust lofted higher in the atmosphere can affect ice cloud properties and induce changes in rainfall via ice nucleation and cloud invigoration processes

DII: dust interacting with ice clouds



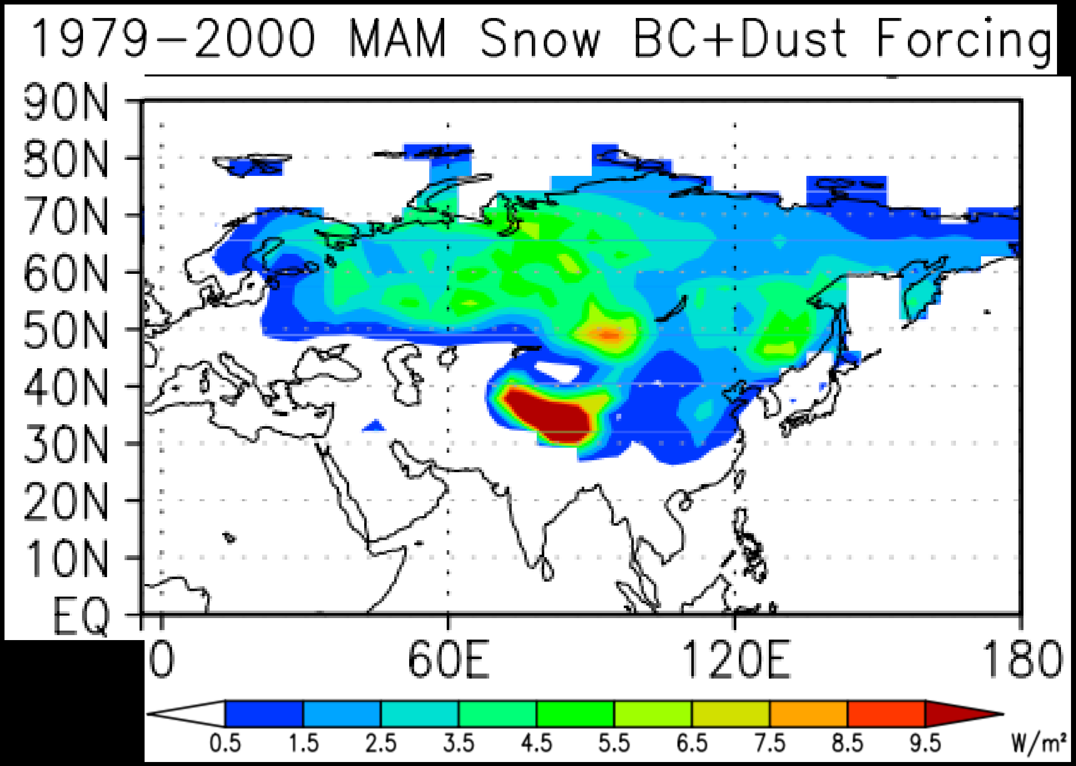




Patel et al., 2019, GRL

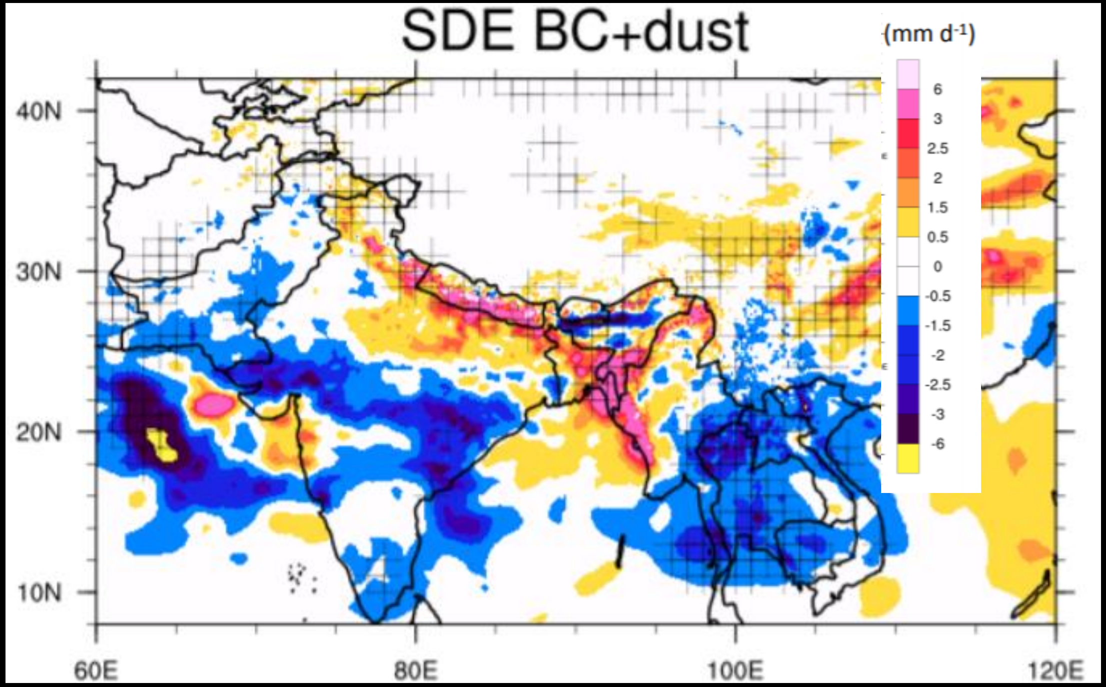
Snow Darkening Effect: Dust/Black Carbon Deposition on snow

- Himalayas-Tibetan Plateau (HTP) are among the largest ice-covered regions on Earth, major freshwater resource in Asia.
- Climate simulations suggest climate warming and accelerated snowmelt in the Himalayas, *due to dust and black carbon deposition.*



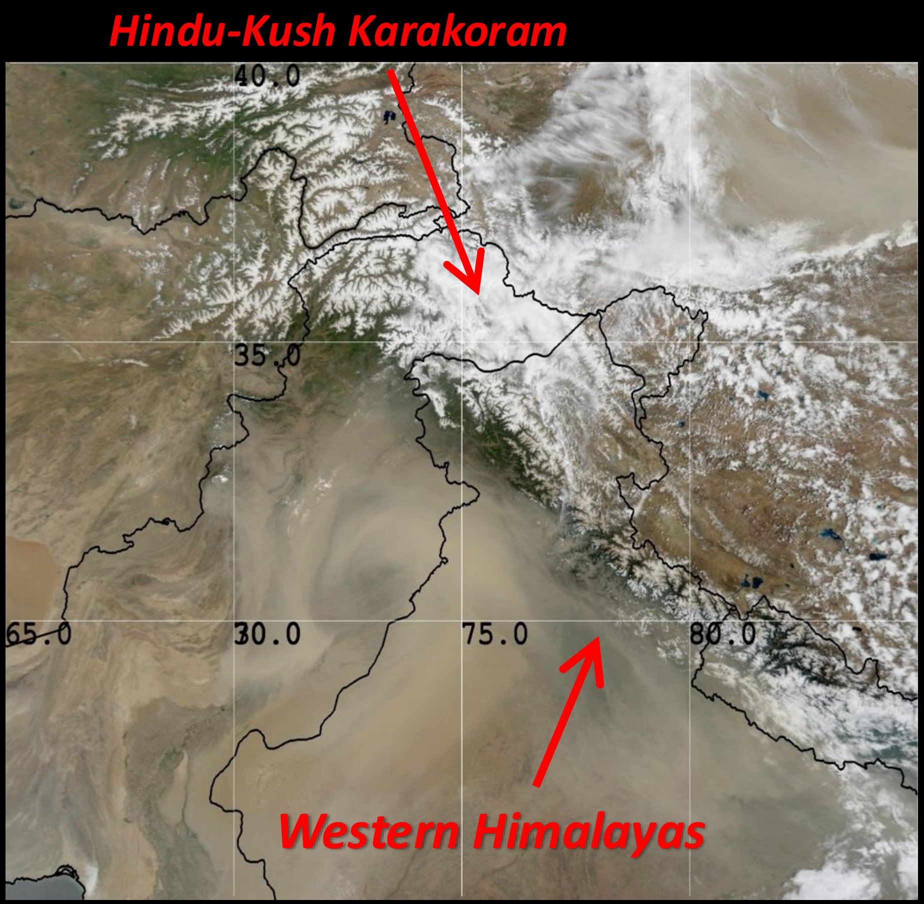
Flanner et al. 2009, *ACP*

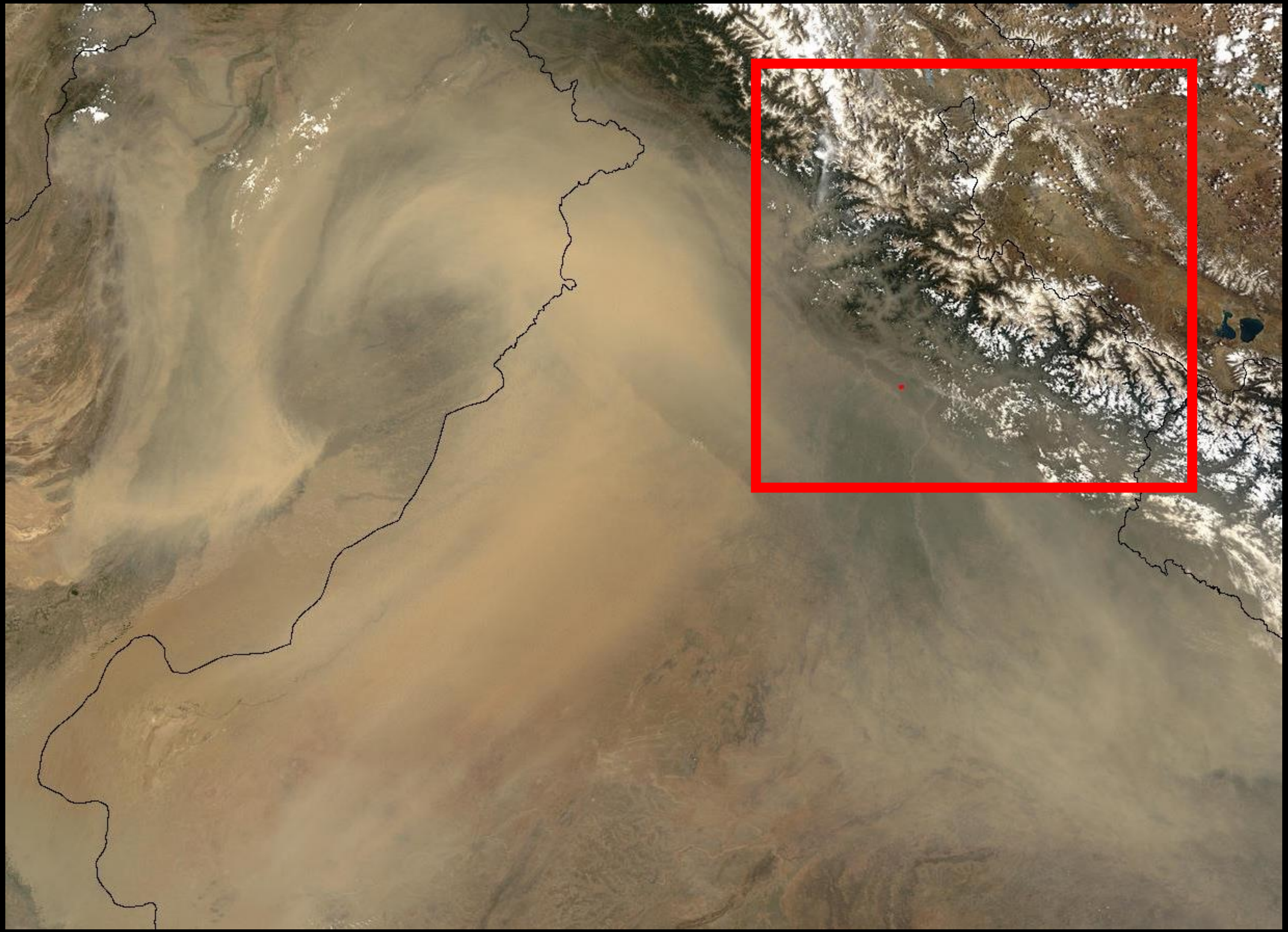
May-June mean precipitation anomaly in response to Snow Darkening Effect



Rahimi et al. 2019, *ACP*

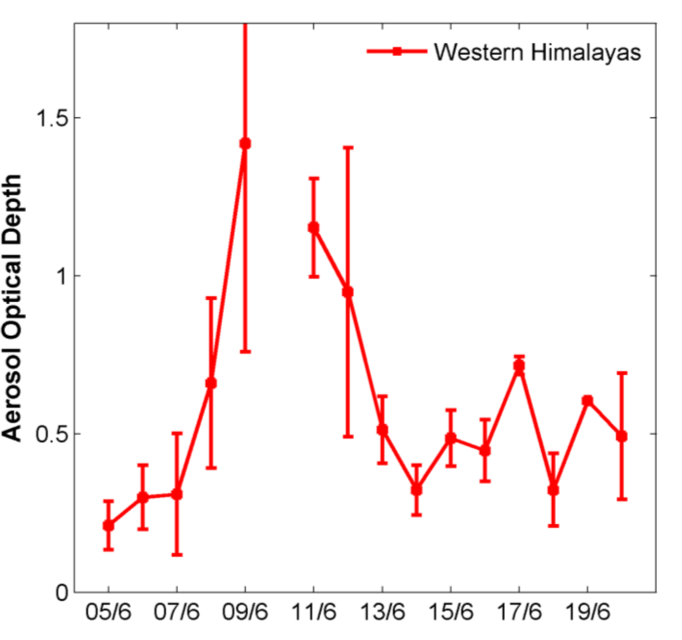
Dust Storm over southern Asia, 9 June 2003



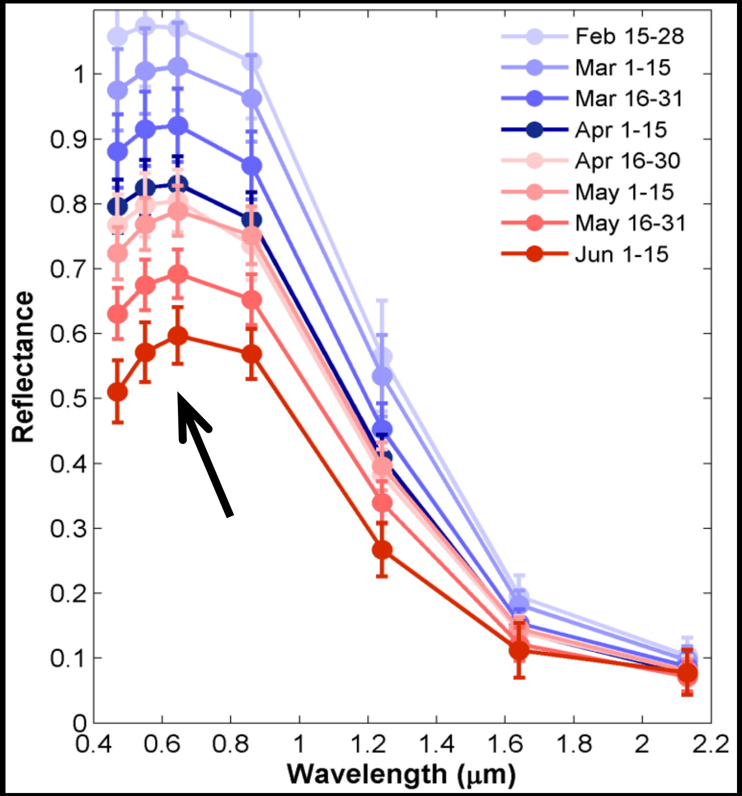


Snow Darkening in the Himalaya

MODIS/Aerosol Optical Depth



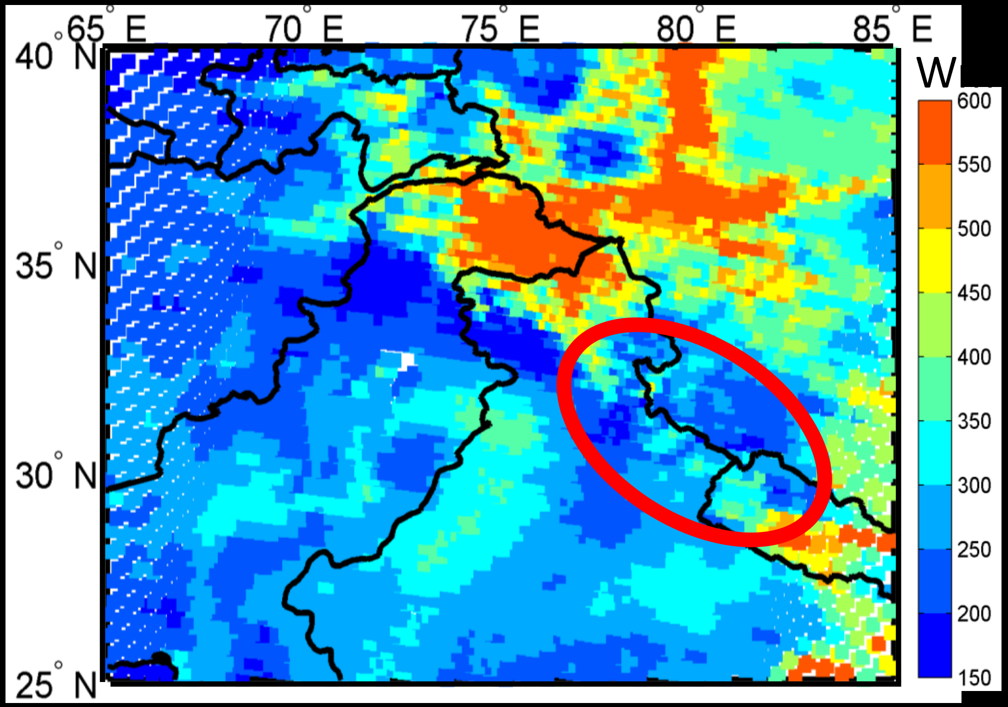
Seasonal variation of Reflectance over western Himalaya Snow



- *Snowmelt/Snow Aging: winter-summer*
- *VIS-NIR gradient in summer*

Shortwave Flux (reflected) Top-of-Atmosphere (CERES)

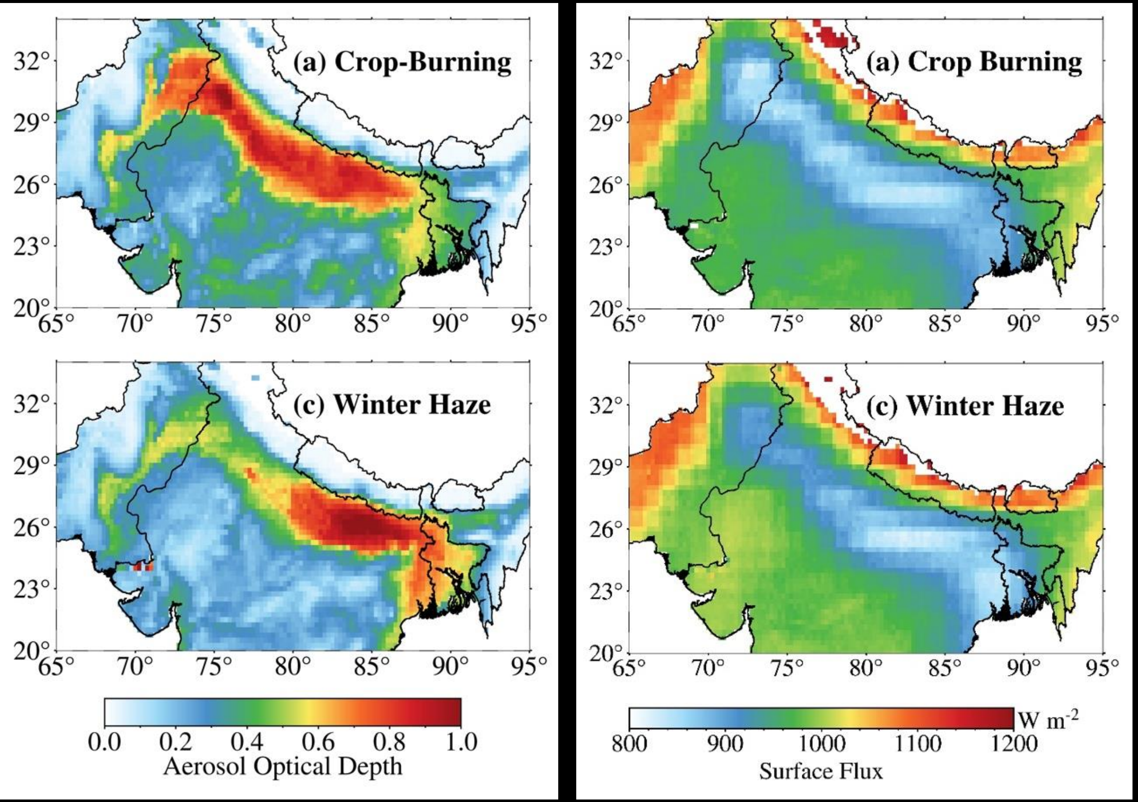
9 June 2003

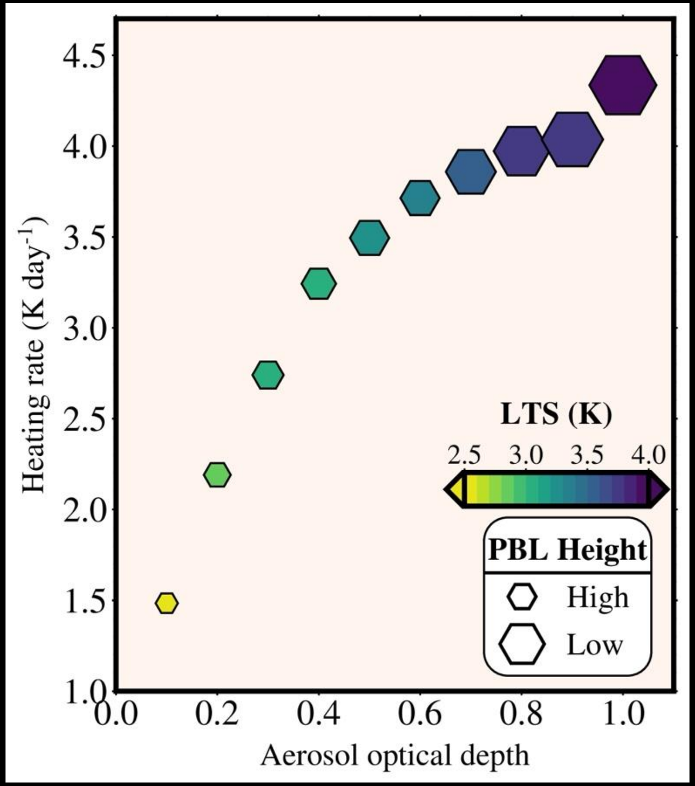


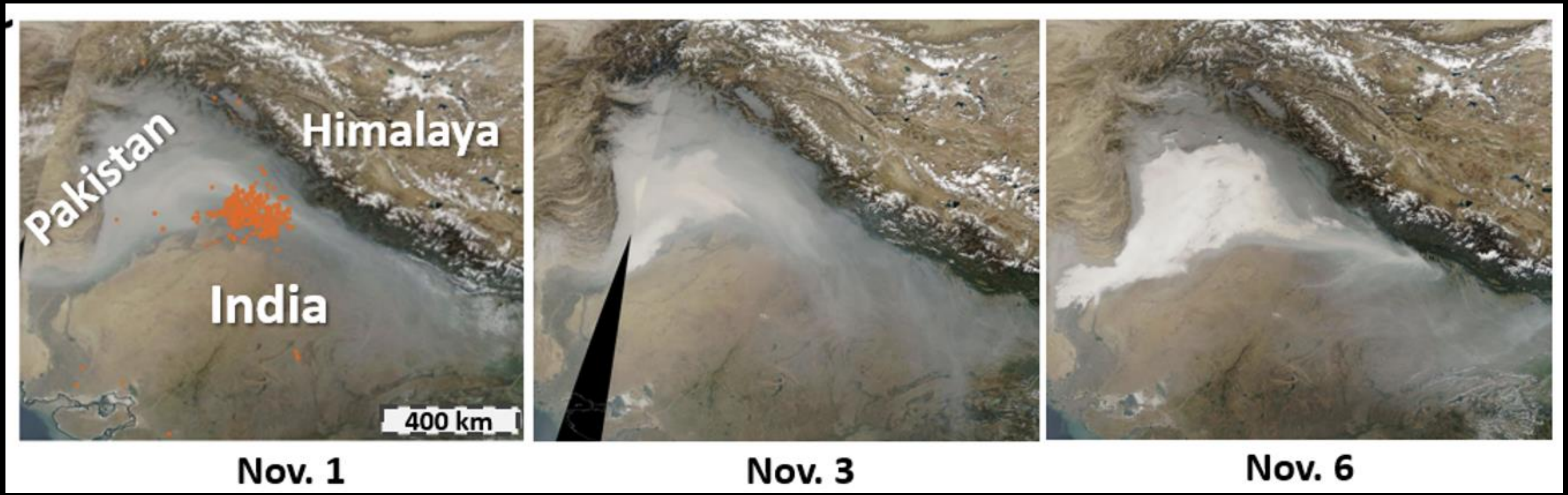
Darkening over dust-laden western Himalaya snow cover with lower TOA flux (250-400Wm^{-2}), compared to northern Hindu-Kush-Karakoram (400-500Wm^{-2}), outside of dust front.

Gautam et al., (2013)

Smog Formation due to aerosol-radiation effects on regional meteorology



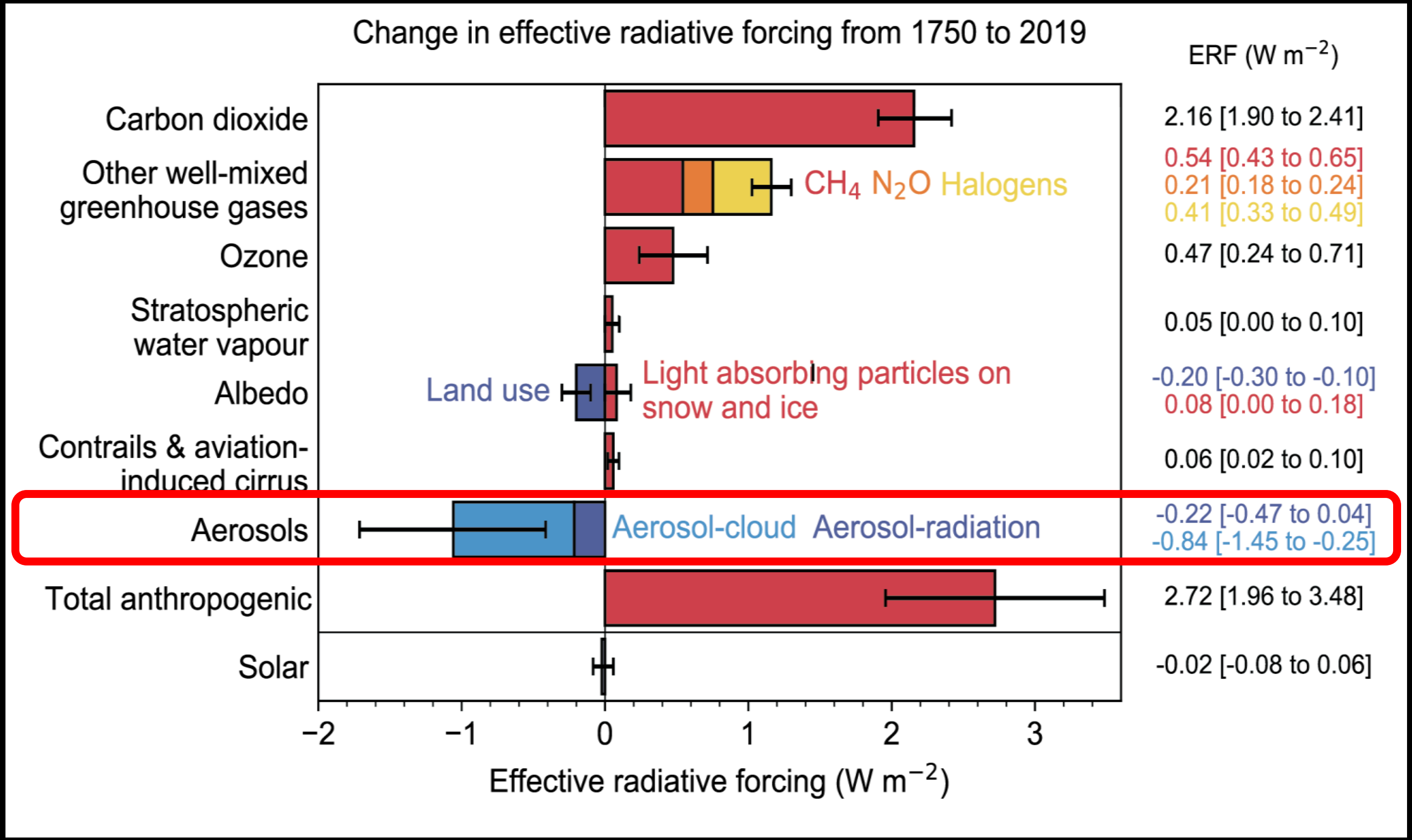


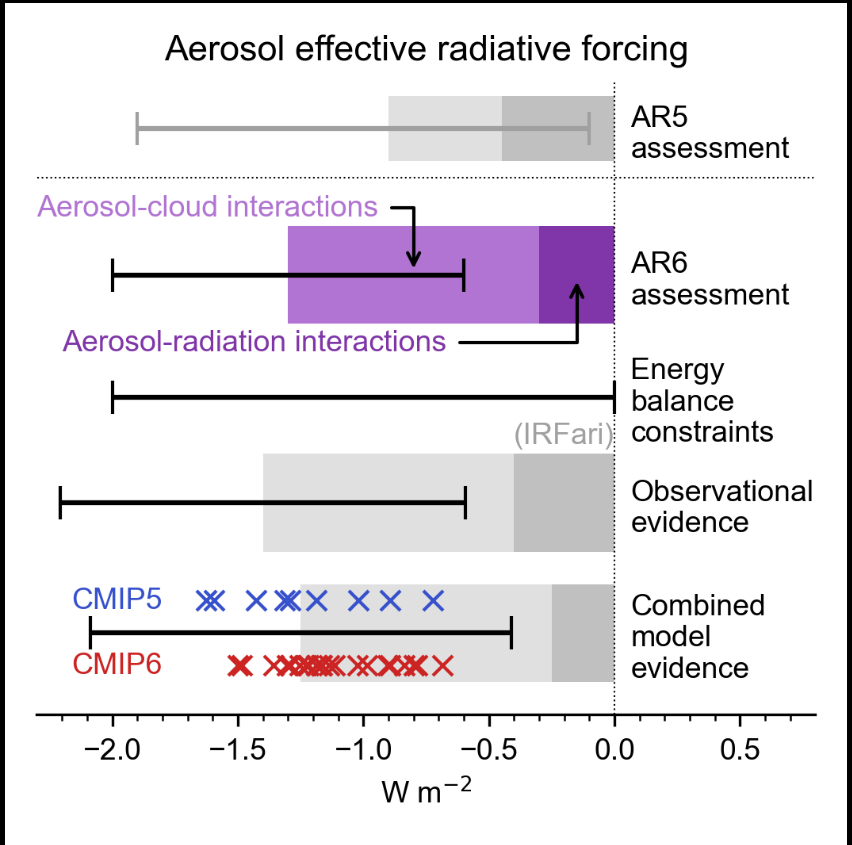


Gautam and Patel et al., 2023, GRL

Why we need to study aerosols?

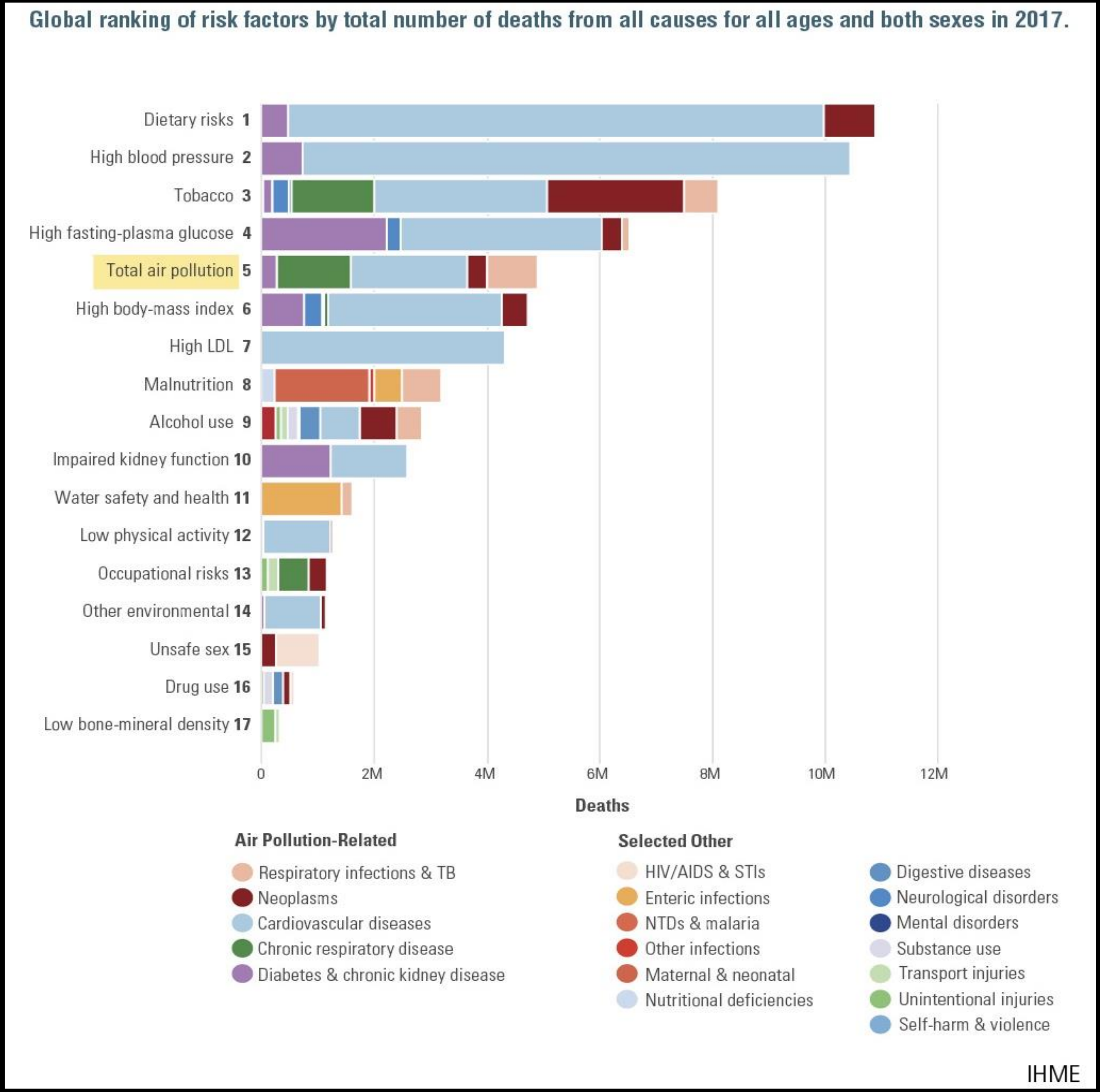
IPCC 2021 (1750– 2019)





Global mean radiative forcing of individual components of the atmospheric as estimated in the IPCC assessment reports.

Why we need to study aerosols?



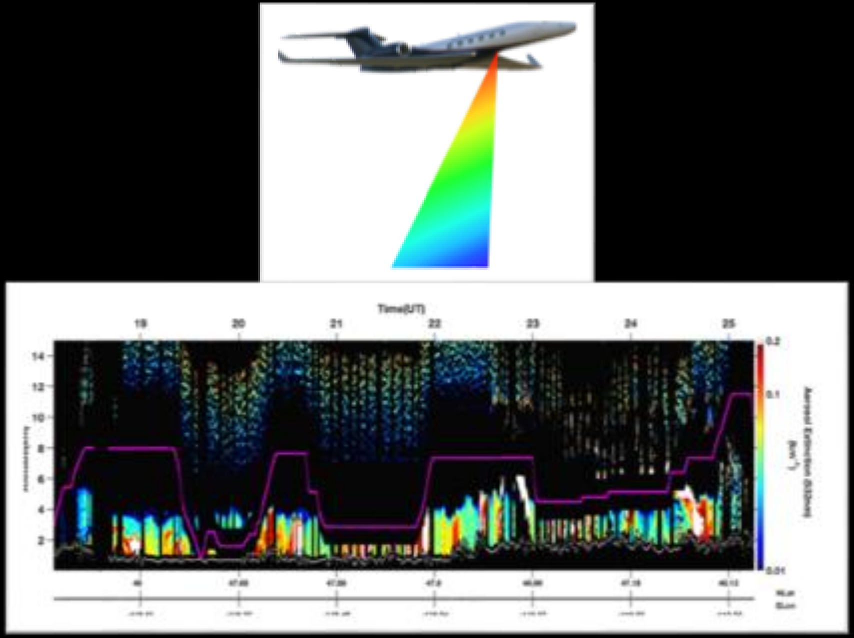
Aerosol Monitoring

Ground-based Remote Sensing

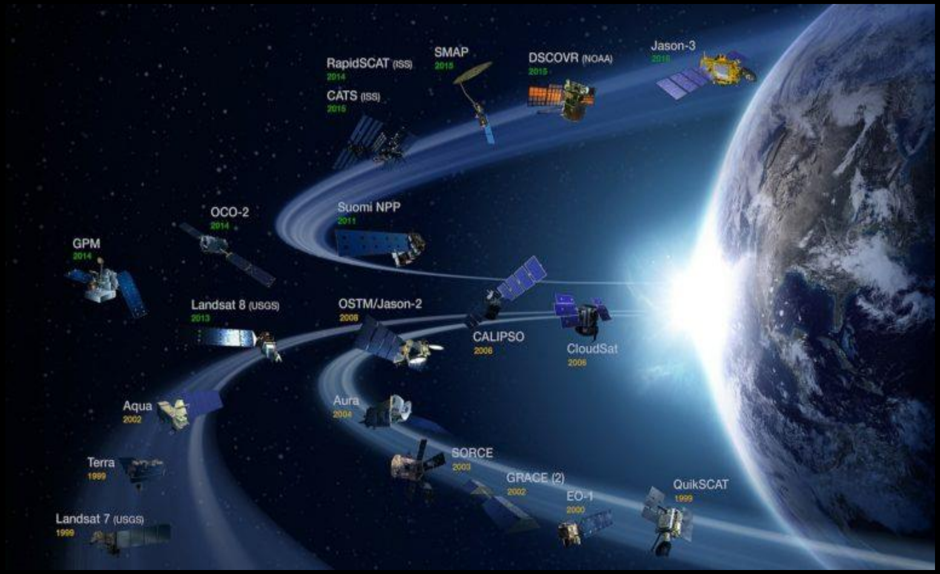
- Microtops II
- Sun/Sky Radiometer
- Scanning Mobility Particle Sizer
- Differential Mobility Particle Sizer
- Condensation Particle Counter
- Aerodynamics Particle Sizer
- Aethalometer
- Scanning electron microscopy
- Liquid/Gas/Ion Chromatography
- Proton Nuclear Magnetic Resonance

Balloon borne Remote Sensing

Airborne Remote Sensing



Satellite Remote Sensing



- MODIS (Terra & Aqua)
- OMI (Aura)
- MISR (Terra)
- CALIOP (CALIPSO)
- TROPOMI (Sentinental-5P)
- VIIRS (S-NPP/NOAA-20/21)
- SPEXone (PACE)
- EarthCARE
- Biomass

- GEOS
- Fengyun series
- Himawari series
- INSAT series

Why Satellite Remote Sensing ?

- **Global Monitoring:** Satellite RS covers the entire Earth, including land, ocean, atmosphere, and cryosphere.
- **High Spatial and Temporal Resolution:** Satellites provide frequent and systematic observations with consistent spatial and temporal coverage.
- **Beyond Ground Limits:** Unlike ground-based measurements, which are limited to specific locations, satellites offer a broader, global perspective.
- **Geophysical Variable Retrieval:** RS facilitates the retrieval of various geophysical variables, enhancing monitoring and analysis across diverse Earth systems.

Why Atmospheric Remote Sensing ?

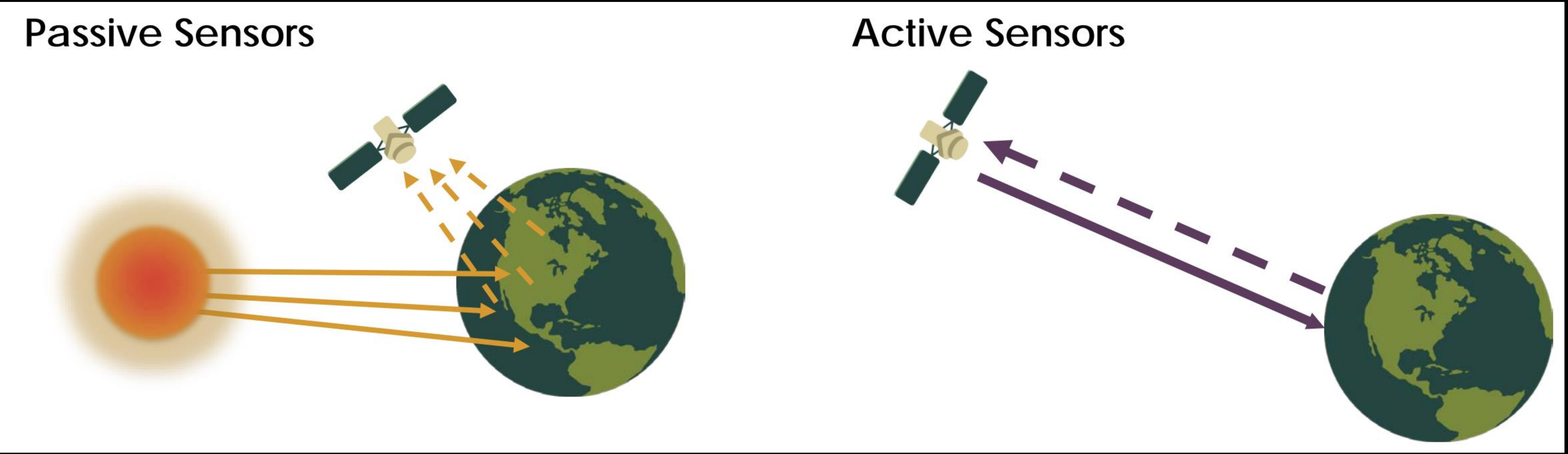
Because there is a global need/concern to understand more about atmosphere, its contents, various processes.

- Monitoring & Retrieval of aerosols, clouds, water vapor, rainfall and so on.
- Atmospheric Correction in satellite/airborne imagery
- Atmospheric data is used for weather forecasting and climate prediction
- Air Quality characterization
- Studying Global & Regional Environmental/Climate Change

Active vs. Passive Remote Sensing

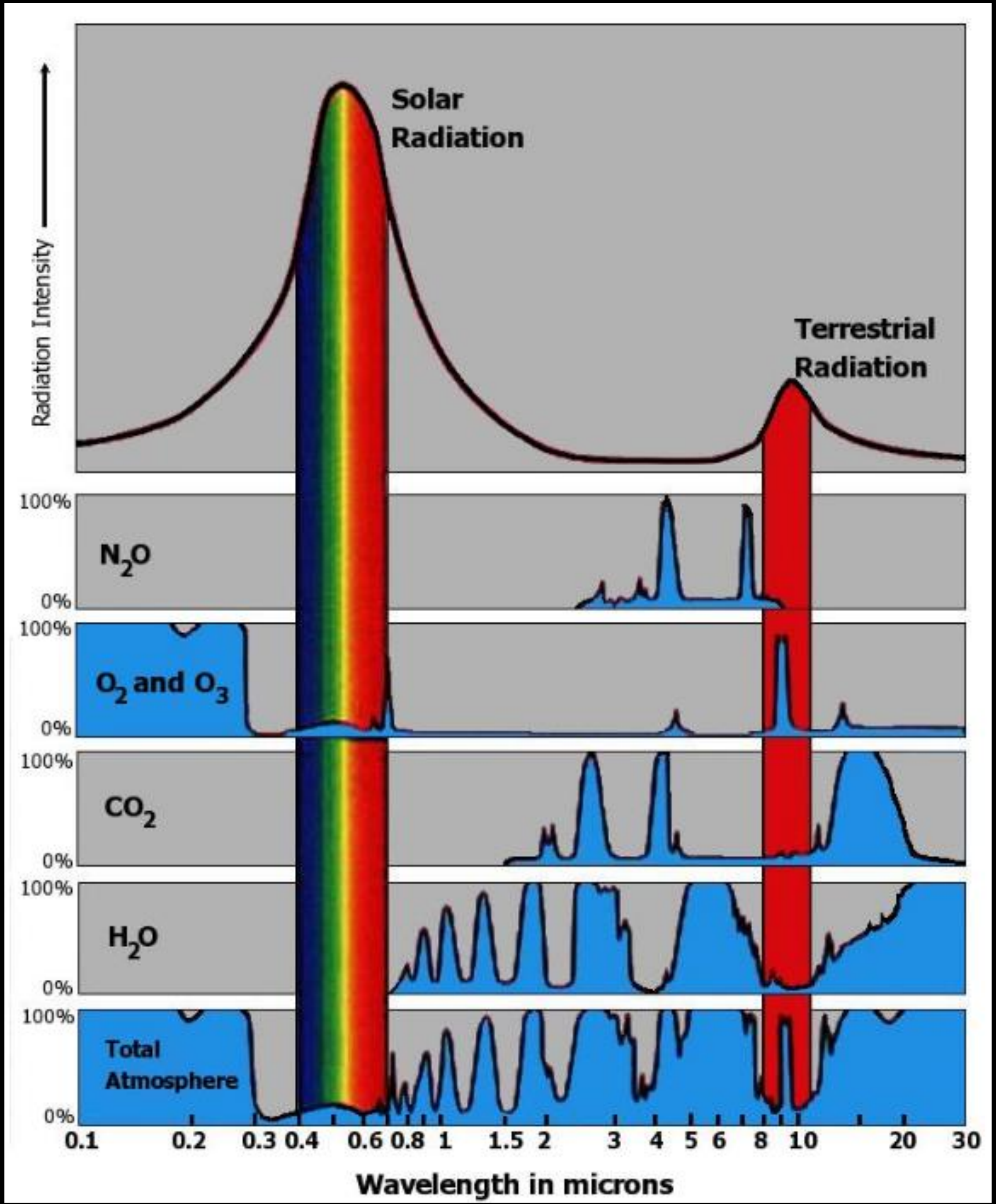
Solar/Terrestrial back-scatter
(sensor depends on backscattered shortwave/longwave radiation)
(MODIS, MISR, POLDER, SPEXone etc.)

Active system
(sensor has its own source of light)
(CALIOP/CALIPSO, ATLID/EarthCARE)



Pros: horizontal coverage
Cons: daytime only,
no vertical information

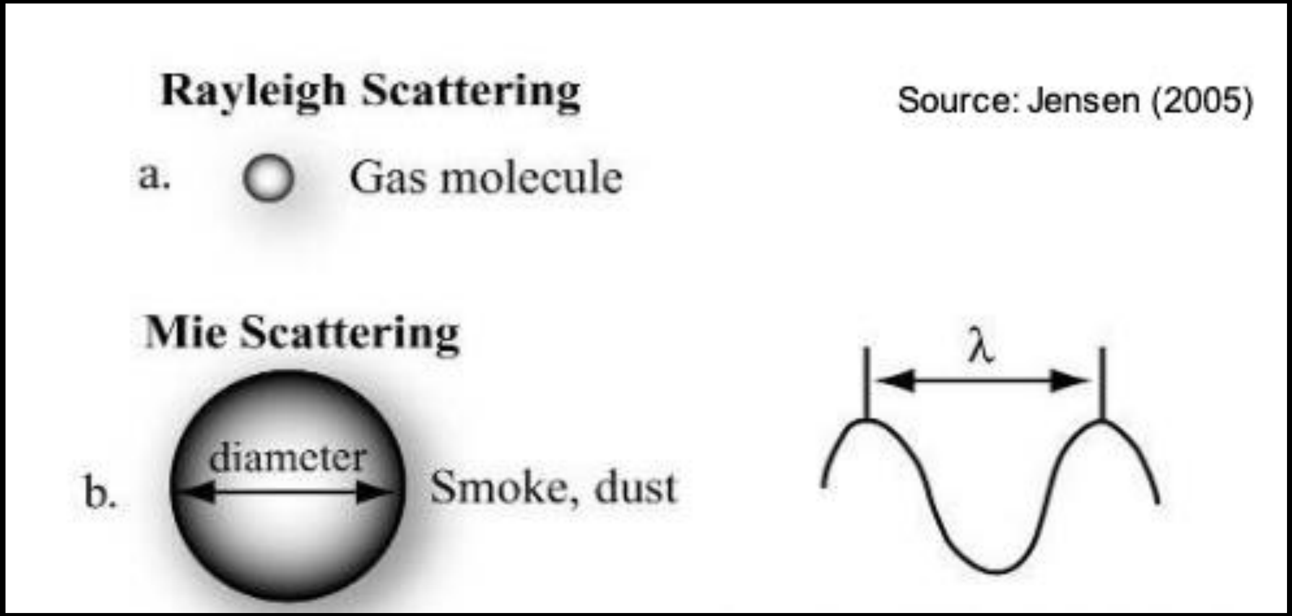
Pros: vertical profiling
Cons: sparse sampling,
low S/N

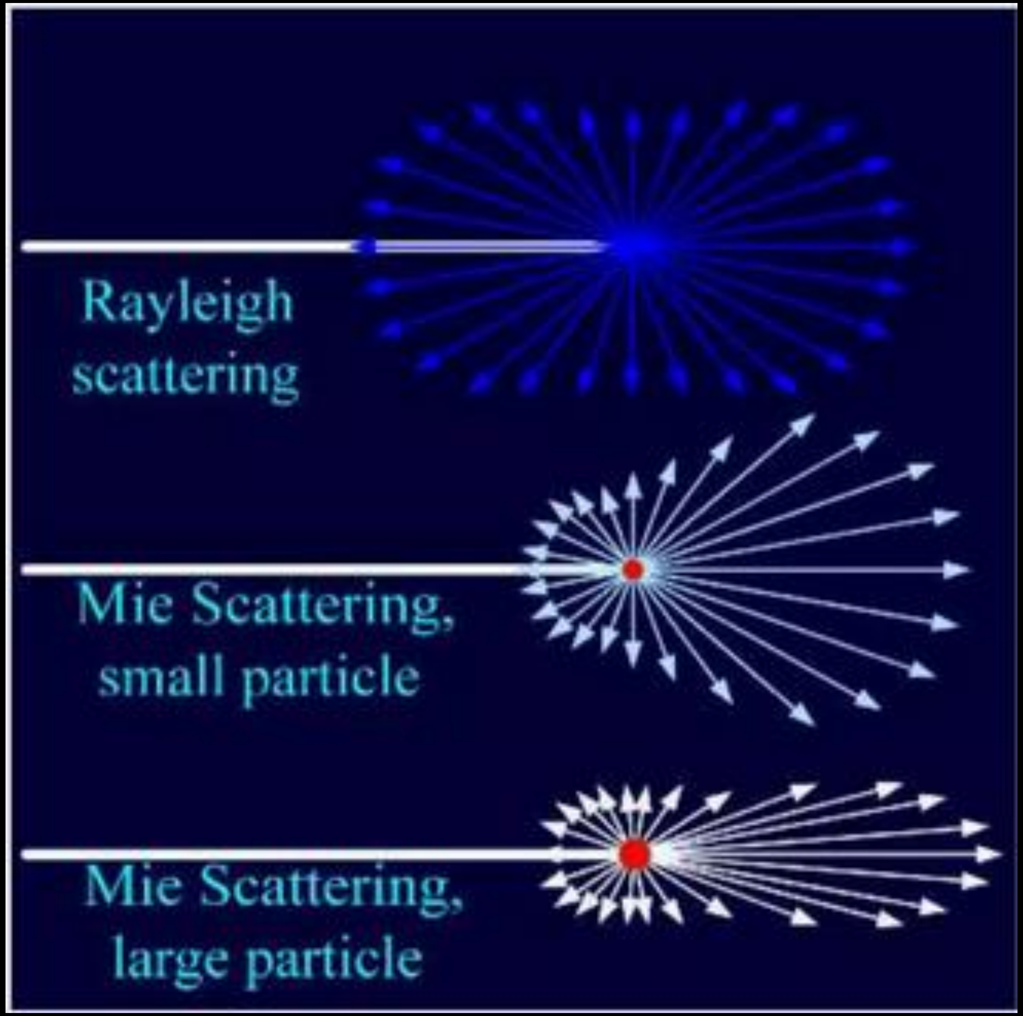


Visible part of Solar Radiation is largely unaffected atmospheric gases, but it is influenced by particle scattering (due to aerosols and clouds).

Longwave radiation is influenced by absorption due to gases present in the atmosphere such as CO2, water vapor, methane, etc.

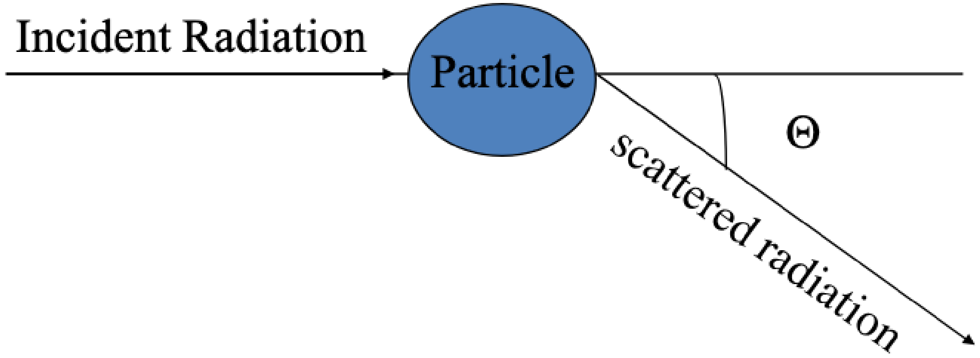
Interactions of Electromagnetic Radiation with Atmosphere





Scattering angle

The scattering angle, Θ, is the relative angle between the incident and the scattered radiation



Phase function

The phase function, P(Θ), describes the distribution of scattered radiation for one or a set of particles. It is normalized such as:

$$\int_0^{2\pi}\int_0^{\pi} P(\Theta)\,d\omega = 4\pi$$

since $$\int_0^{2\pi}\int_0^{\pi} P(\Theta)\sin(\theta)\,d\theta\,d\phi = 2\pi\int_0^{\pi} P(\theta)\sin(\theta)\,d\theta$$

we have $$\int_0^{\pi} P(\theta)\sin(\theta)\,d\theta = 2$$

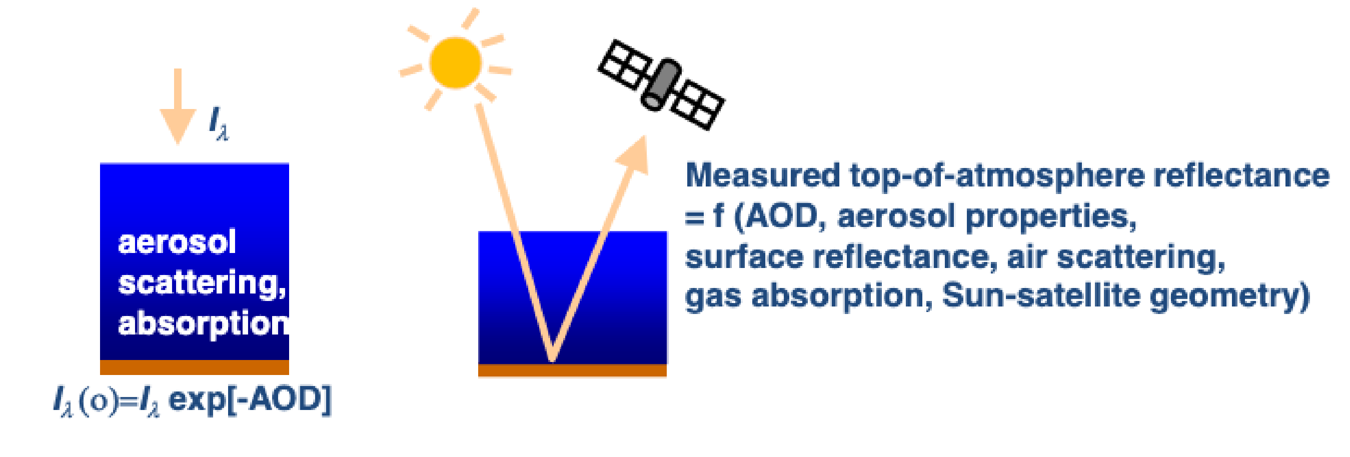
Aerosol Impact on At-sensor Reflectance (Top-of-Atmosphere)

At-sensor reflectance, Apparent Reflectance and Top-of-Atmosphere (TOA) Reflectance imply the same quantity

California fire plumes

Pollution off U.S. east coast

Dust off West Africa

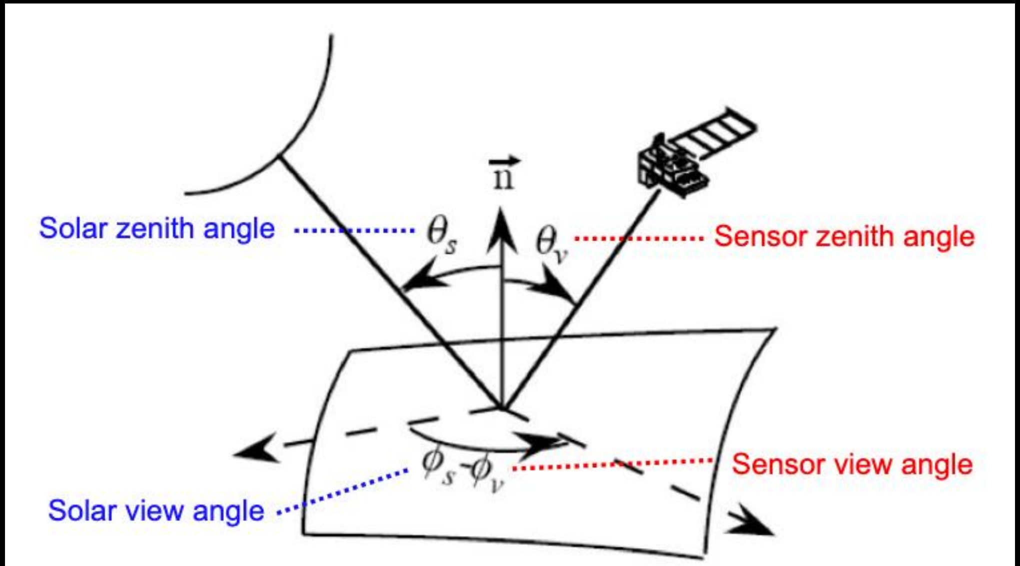


Over which surface (ocean, vegetation, desert) are aerosols most easily detectable??

Principle of Aerosol Remote Sensing

$$R(\mu, \mu_0, \phi) = \frac{\pi I(\mu, \mu_0, \phi)}{\mu_0 \, F_0}$$

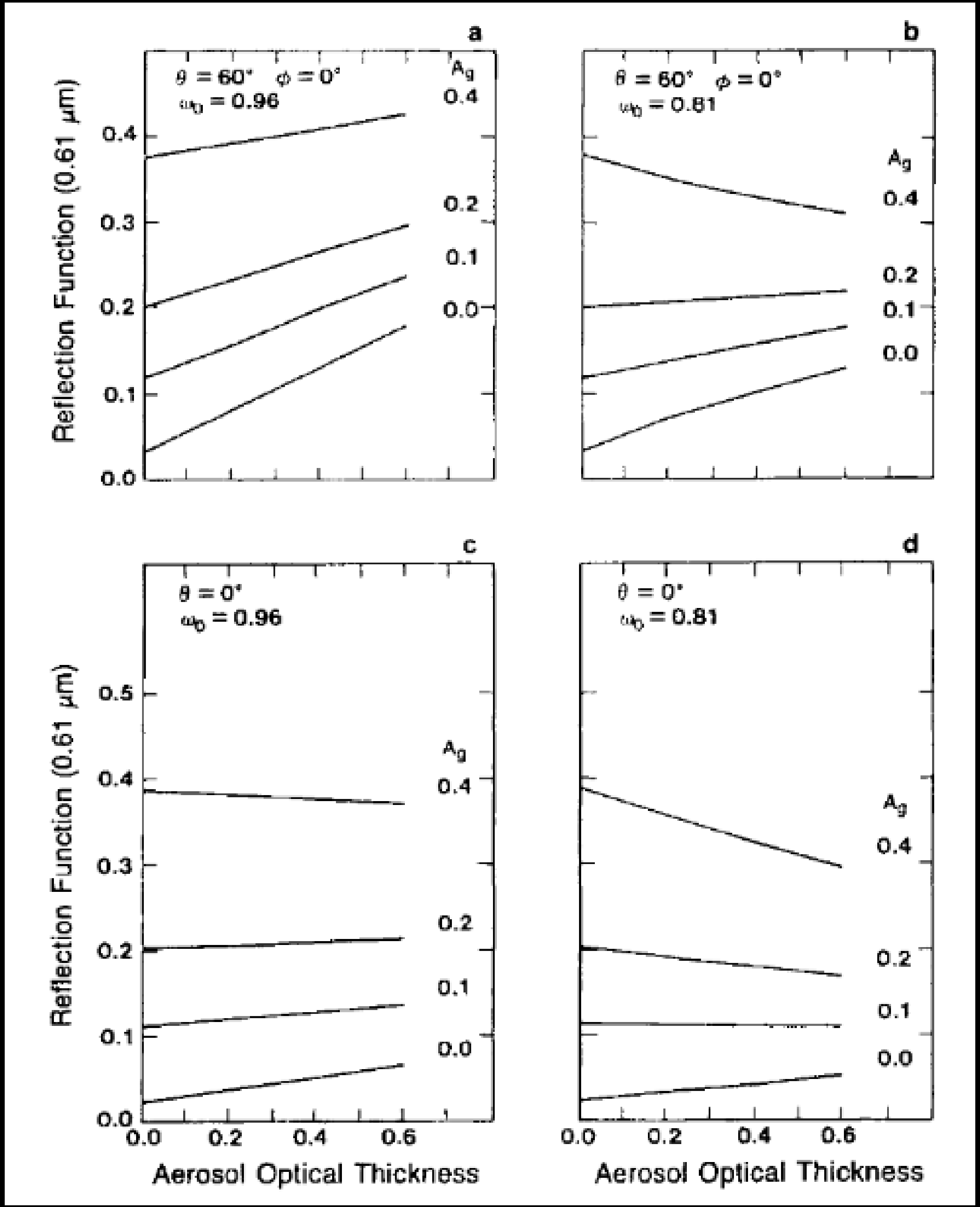
where *R* is the normalized radiance (or apparent reflectance), F_o is the extraterrestrial solar flux, *I* is the radiance at the top of the atmosphere, μ is the cosine of the view zenith angle, μ_o is the cosine of the solar zenith angle, and *φ* is the relative azimuth angle between the direction of propagation of scattered radiation and the incident solar direction



$$R(\mu, \mu_0, \phi) = \underbrace{R_0(\mu, \mu_0, \phi)}_{\text{Purely Atmosphere}} + \underbrace{\frac{T \, A_s}{1 - s \, A_s}}_{\text{Surface Contribution}}$$

where $R_0(\mu, \mu_0, \phi)$ represents the path radiance, T is the transmission function describing the atmospheric effect on upward and downward radiance, A_s is the Lambertian reflectance, and s is the spherical albedo of the atmosphere for illumination from below.

‘s’ is the fraction of the upward flux reflected back to the surface by the atmosphere



Changes in TOA Reflectance as a function of aerosol absorption and surface reflectance

changes in Top-of-Atmosphere Reflectance (Reflection Function), on y-axis, as a function of Aerosol Optical Thickness (or depth), on x- axis, as well as due to changes in surface reflectance (A_g).

The reflection function as a function of aerosol optical thickness and surface reflectance. The changing slope of each line depends on variations in surface reflectance.

King et al. 1999

Principle of Aerosol Remote Sensing From Space

Two Key assumptions:

- Reliable Atmospheric Aerosol Model / Type

  …AOD, SSA, Phase Function, etc.

- Parameterization of Surface Characteristics

  … Primarily Surface Reflectance

Transfer of Radiation through the atmosphere

(Successive Orders of Scattering method, Vermote et al. 2002, 6S radiative transfer code)

Atmospheric reflectance (or path reflectance/radiance)

Ground reflectance

$$\rho(\theta_s,\theta_v,\phi) = \rho_{atm}(\theta_s,\theta_v,\phi) + T_{atm}(\theta_s)\cdot T_{atm}(\theta_v)\frac{\rho_{ground}}{1-\rho_{ground}S_{atm}}$$

Atmospheric Transmissions

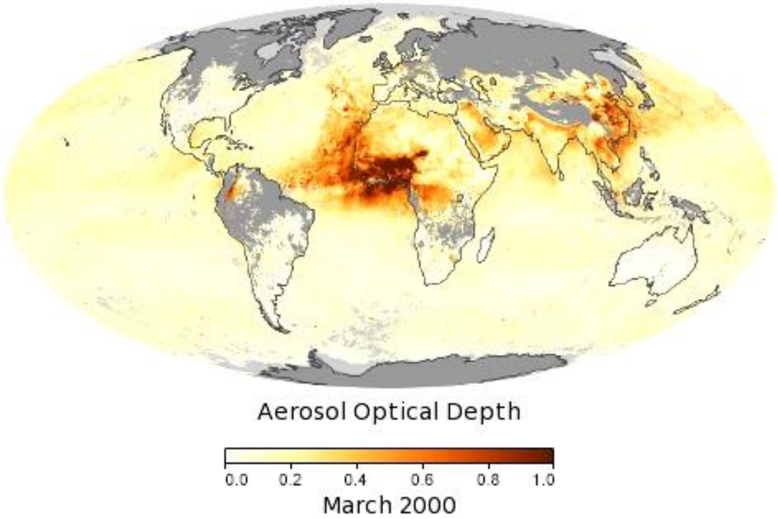
Reflectance at Top of Atmosphere (TOA)

Atmosphere albedo

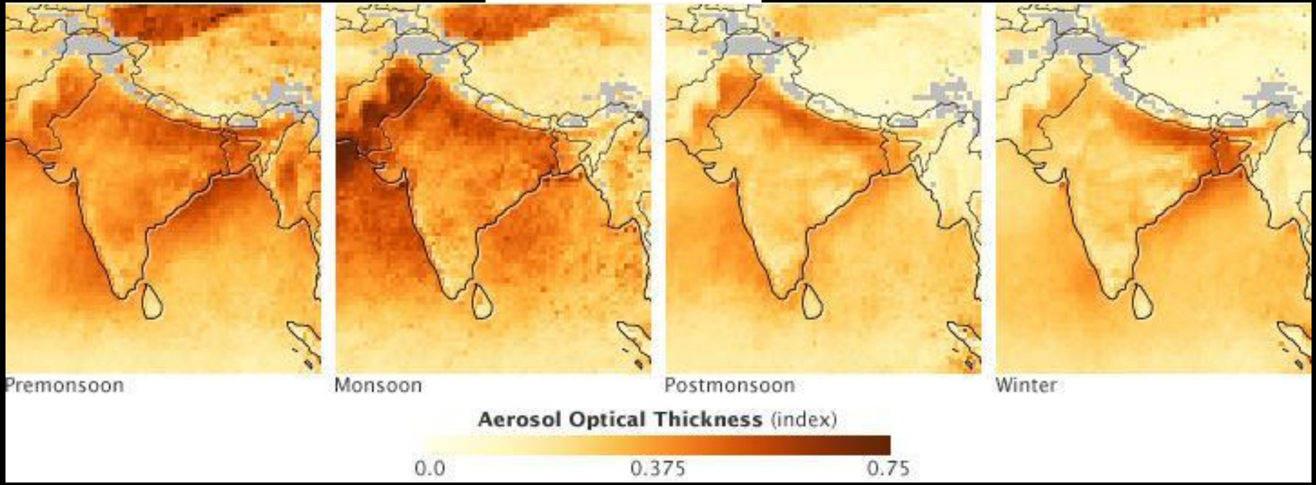
aerosol inversion

Aerosol Monitoring From Satellite

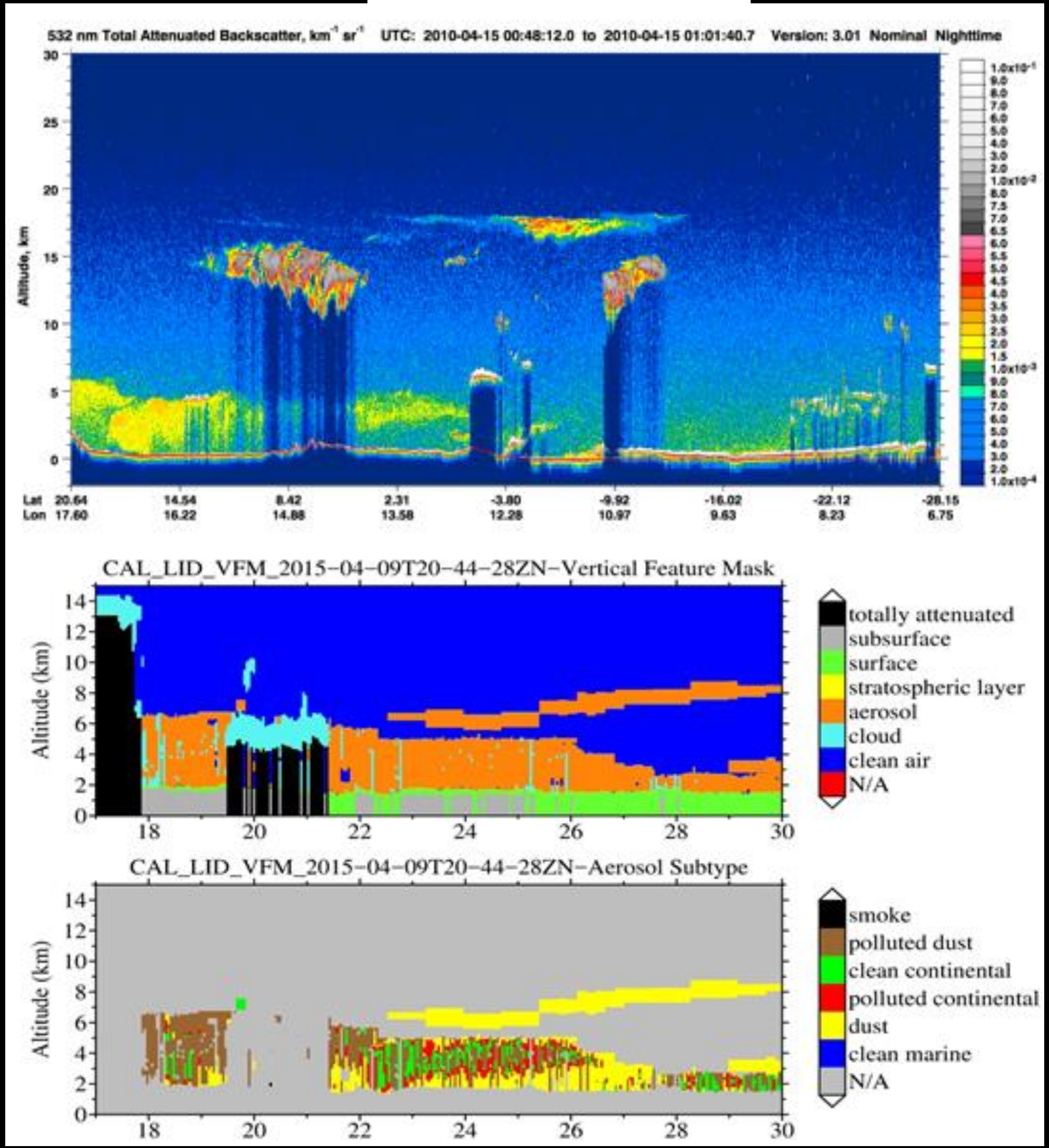
MODIS (Terra)



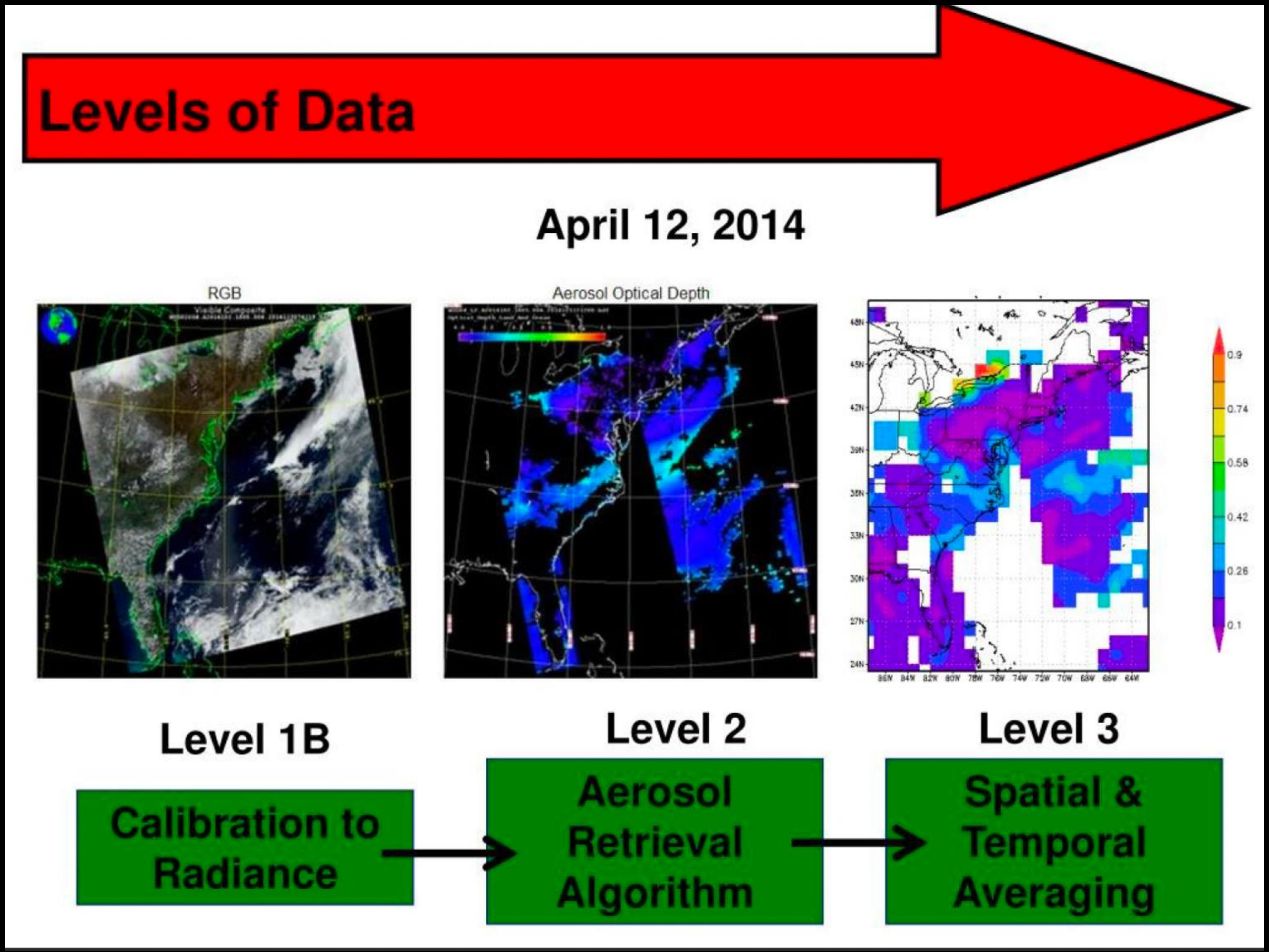
MISR (Terra)



CALIOP (CALIPSO)



Levels of Satellite Data Product



Data Product Hierarchy

Level 1 Products - Raw data with and without applied calibration.

– **NO AEROSOL DATA**

Level 2 Products - Geophysical Products

- **AEROSOL DATA**

Level 3 Products - Globally gridded geophysical products

- **AEROSOL DATA**

Satellite Products for Aerosol

- Aerosol optical depth – MODIS, MISR, VIIRS, TROPOMI, SPEXone
- Angstrom exponent – MODIS, VIIRS, SPEXone
- UV aerosol index– OMI, TROPOMI, SPEXone
- Single scattering albedo– OMI, TROPOMI, SPEXone
- Aerosol layer height – TROPOMI, CALIPSO, SPEXone, EarthCARE
- Vertical profile of aerosol backscatter and extinction coefficient – CALIPSO, EarthCARE

Derived Products

- Refractive Indices (real + imaginary) - SPEXone
- size distributions – SPEXone, CALIPSO, EarthCARE
- Cloud condensation nuclei - SPEXone, CALIPSO, EarthCARE

The extinction coefficient (b_{ext}) represents the sum of the extinctions from gases and particles, each of which can in turn be divided into extinction due to absorption or scattering.

$b_{ext} = b_{gas} + b_{particles}$ (extinction due to gases and particles)
$b_{ext} = b_{abs} + b_{scatt}$ (extinction refers to attenuation of light due to absorption and scattering)

b_{abs} (gases) = Beer's Law absorption
b_{scatt} (gases) = Rayleigh Scattering
b_{abs} (particles) = Usually < 10% of extinction
b_{scatt} (particles) = Mie Scattering = (b_{sp})

Aerosol optical depth (AOD), $\boldsymbol{\tau}$ is a measure of the extinction caused by scattering and absorption, where 'z' is the altitude (typically z ranges from surface to top of atmosphere):

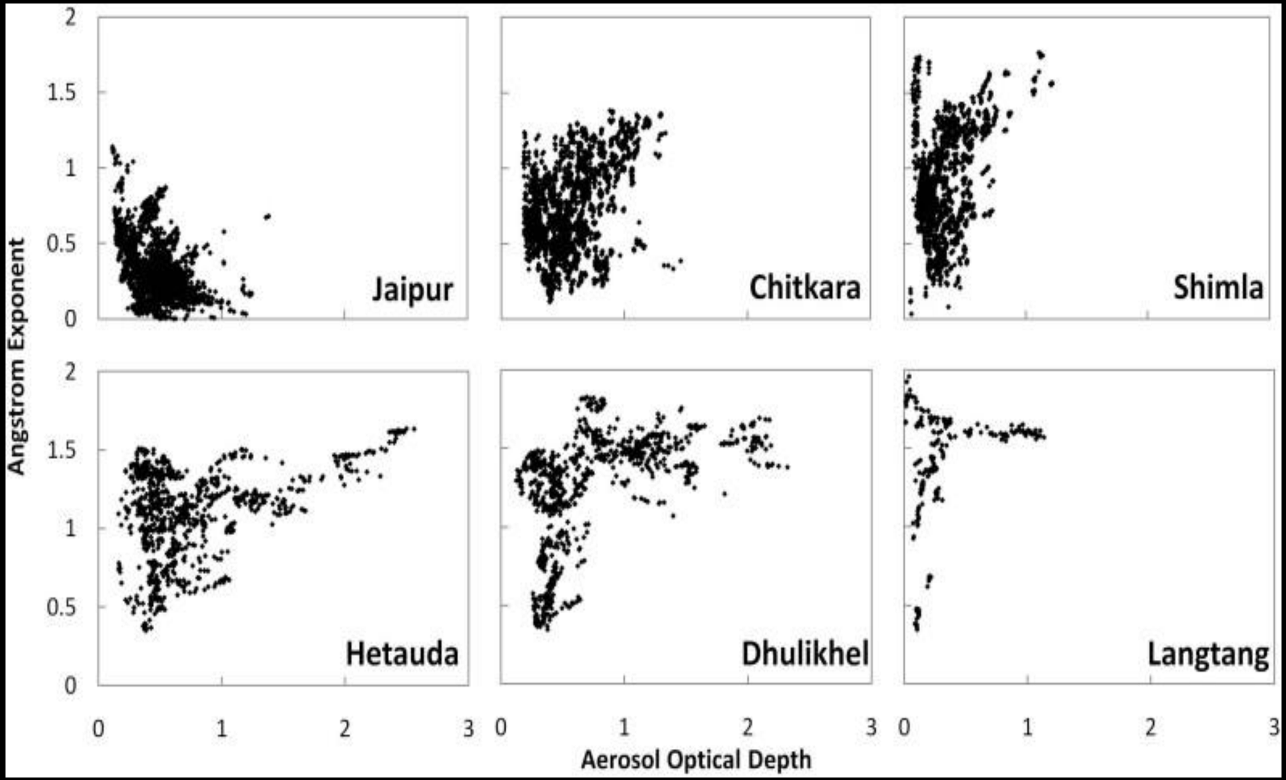
$$\boldsymbol{\tau} = \int b_{ext}(z)\, dz \text{ (unitless)}$$

AOD is unitless. The integral is from surface to top of atmosphere.

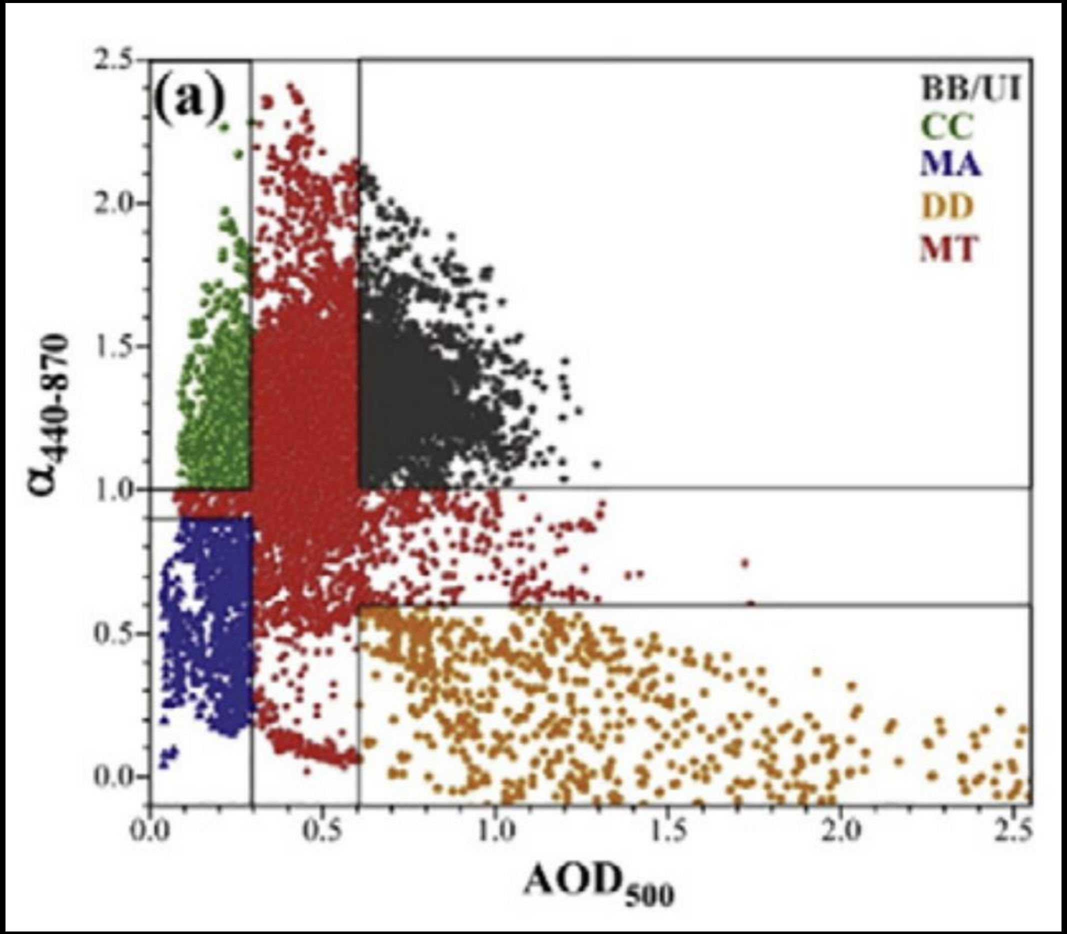
Angström exponent, α, is a measure of the size distribution, describes the dependency of the aerosol optical thickness on wavelength. For urban aerosols (fine particles) $\alpha > 1.0$, for dust storms (coarse particles) $\alpha << 1.0$. (λ_0 is shorter wavelength while λ is longer wavelength)

$$\frac{\tau_\lambda}{\tau_{\lambda_0}} = \left(\frac{\lambda}{\lambda_0}\right)^{-\alpha}$$

$$\alpha = -\frac{\ln \frac{\tau_\lambda}{\tau_{\lambda_0}}}{\ln \frac{\lambda}{\lambda_0}}$$



Gautam et al. 2011, ACP



Patel et al., 2017

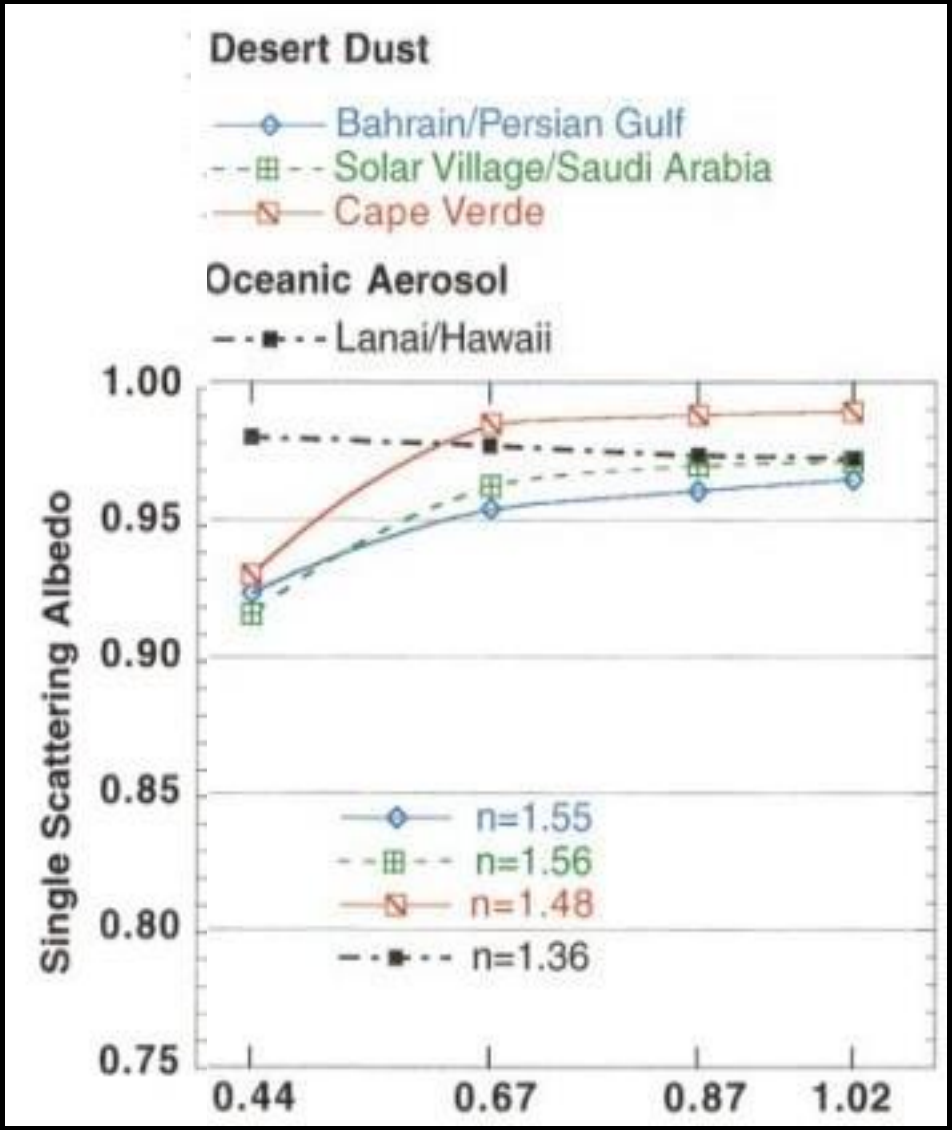
Single scattering albedo, ω, is a measure of the fraction of aerosol extinction caused by scattering:

$$\omega = b_{scatt}/(b_{scatt} + b_{abs})$$

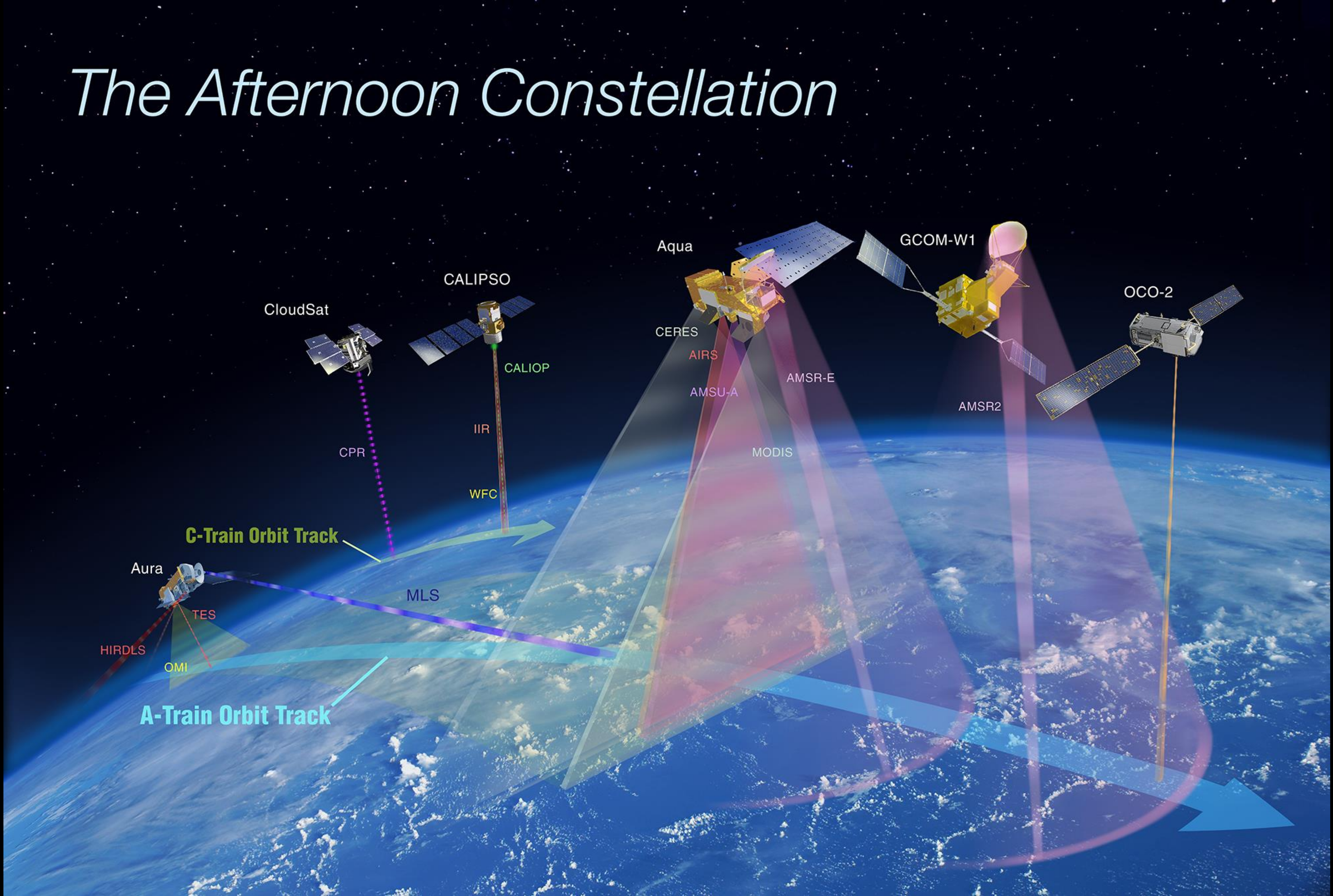
b_{scatt} is scattering coefficient
b_{abs} is absorption coefficient

Single Scattering Albedo (SSA) value of aerosols ranges from 0 to 1. SSA=1 means 100% scattering aerosol (with no absorption).

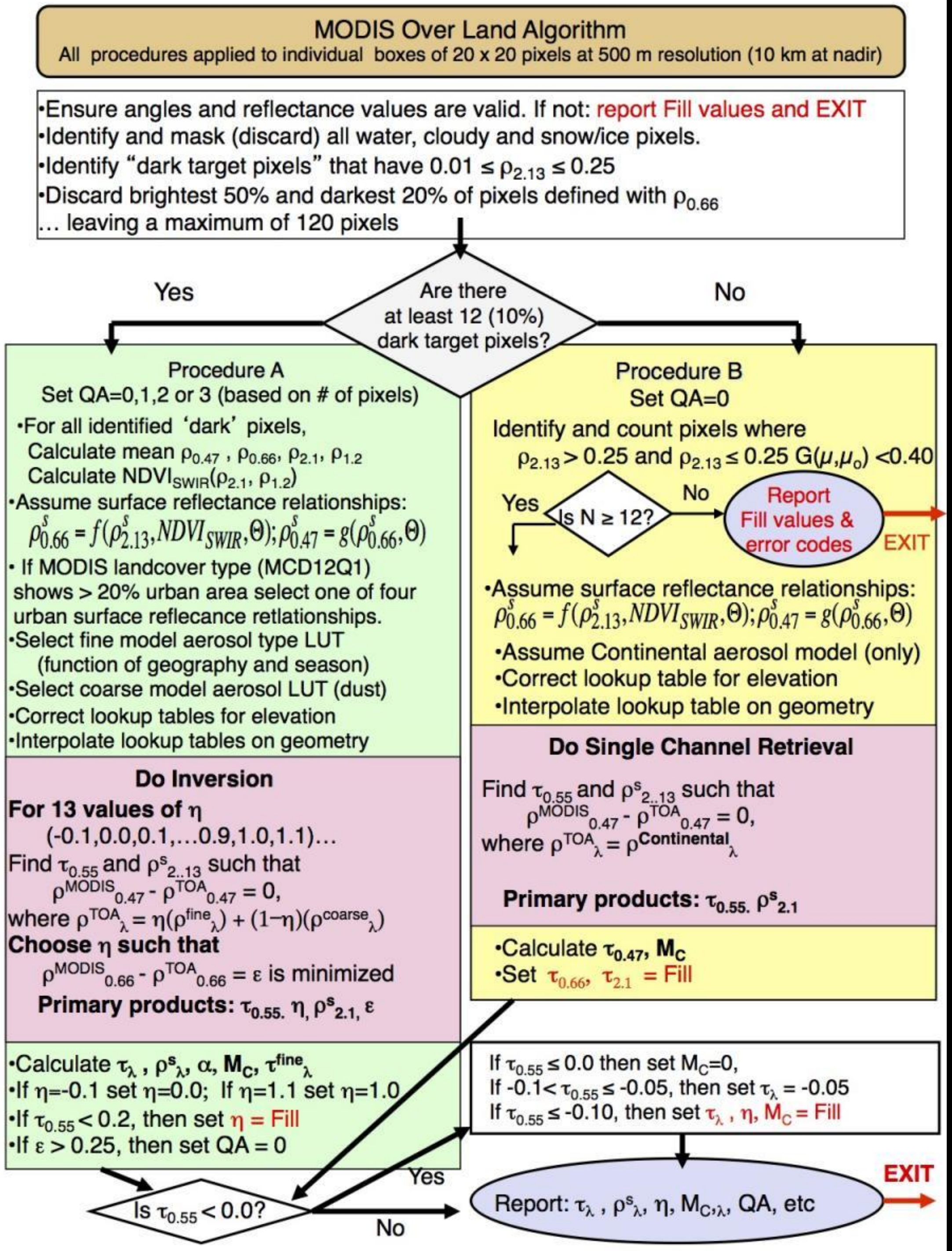
More Light-absorbing aerosol



Dubovik et al. 2002

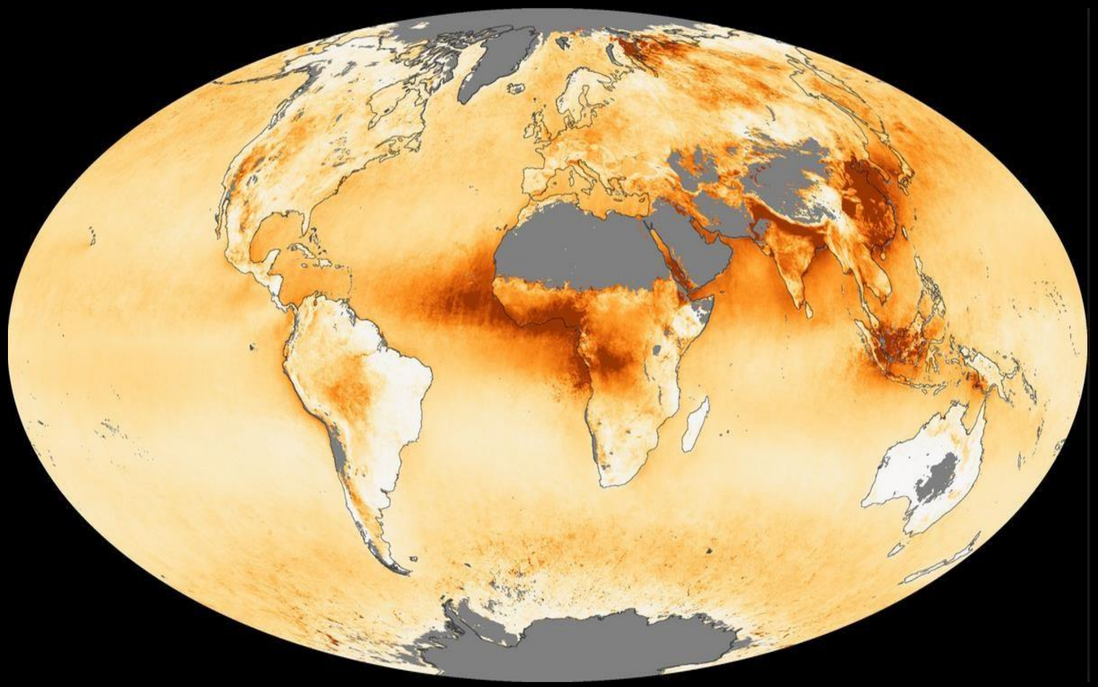

The Afternoon Constellation
Aqua
GCOM-W1
CALIPSO
OCO-2
CloudSat
CERES
AIRS
CALIOP
AMSR-E
AMSU-A
AMSR2
IIR
CPR
MODIS
WFC
C-Train Orbit Track
Aura
MLS
TES
HIRDLS
OMI
A-Train Orbit Track

	MODIS	VIIRS
Spatial resolution	10 km 3 km	6 km
Aerosol products	• aerosol optical depth • Angstrom exponent • aerosol types	• aerosol optical depth • Angstrom exponent • aerosol types
Algorithms	• Dark target aod • Deep blue aod • Ocean aod	• Dark target aod • Deep blue aod • Ocean aod



MODIS Dark Target AOD

Aerosol retrieval algorithm is a complex inversion scheme where assumptions are made in simulating satellite observations with advance radiative transfer calculations to retrieve atmospheric aerosol properties



In the Dark-Target retrieval algorithm, aerosols are retrieved over dark surfaces (vegetation, ocean), resulting in gaps over bright surfaces (deserts, above clouds and snow)

Remer et al., 2005, Levy et al., 2013

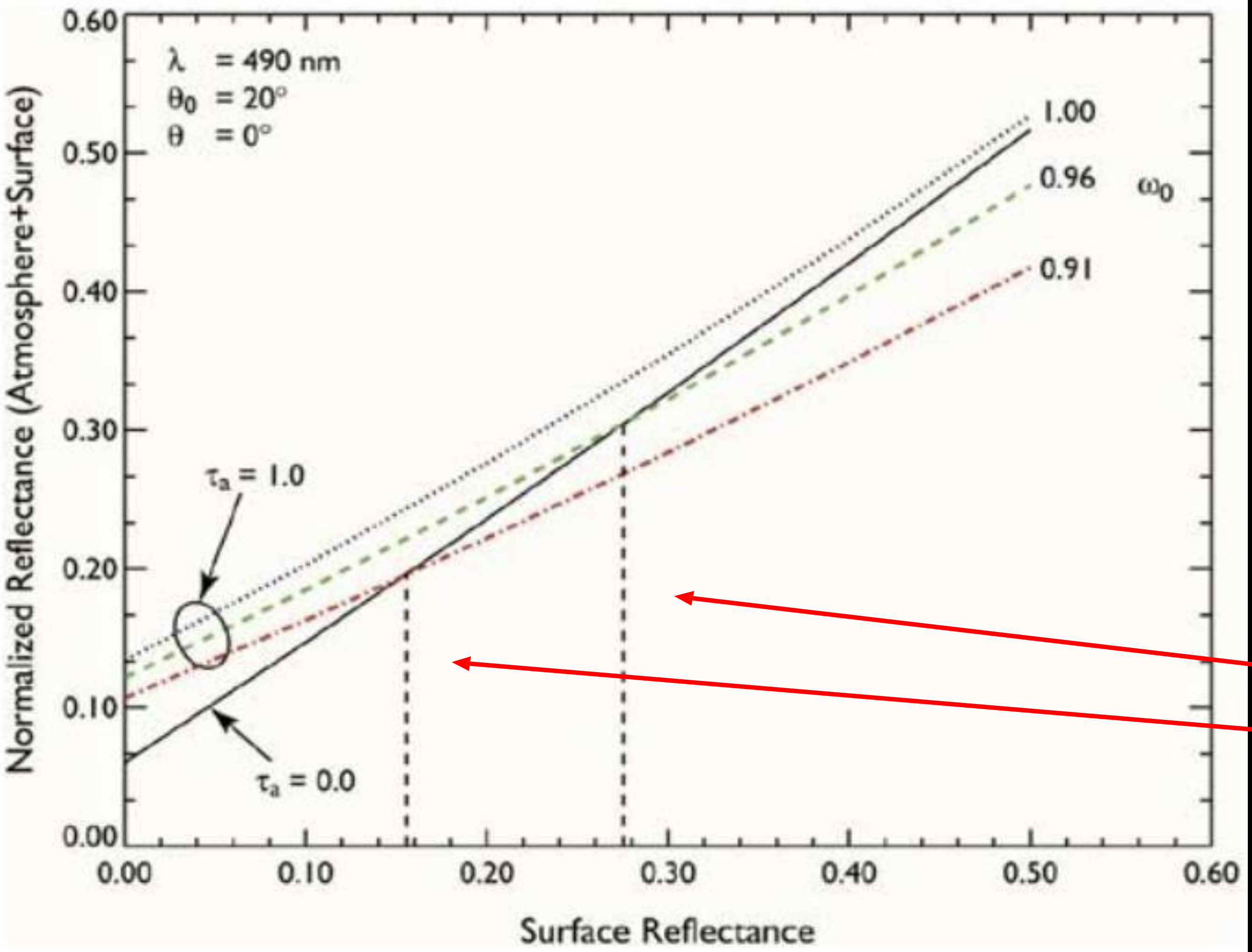


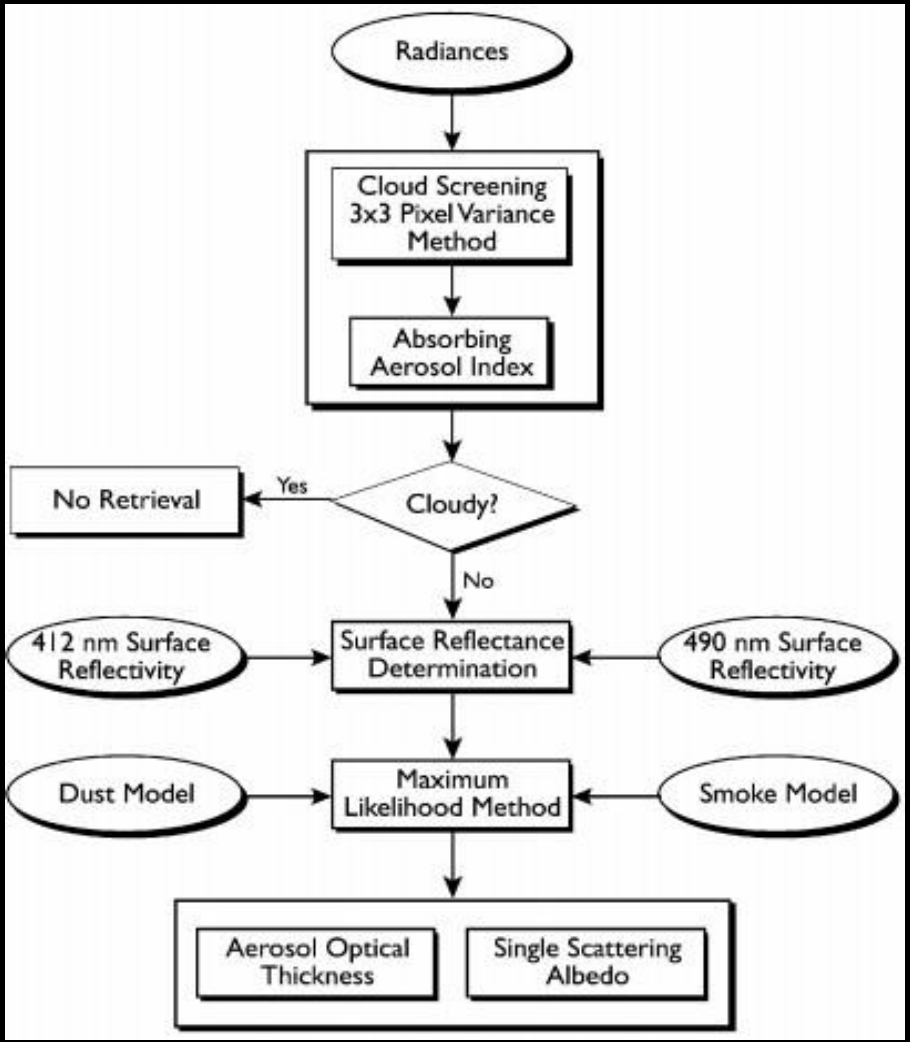
Fig. 1. Simulated apparent reflectance (atmosphere + surface) at the top of the atmosphere at 490 nm, as a function of surface reflectance for various values of the aerosol optical thickness τ_a and single-scattering albedo ω_0. The black solid line represents the apparent reflectance without aerosol, and the black dotted, green, and red lines represent the apparent reflectance with $\tau_a = 1.0$. The vertical lines denote the critical values of surface reflectance where the presence of aerosol cannot be detected by satellite for selected values of ω_0.

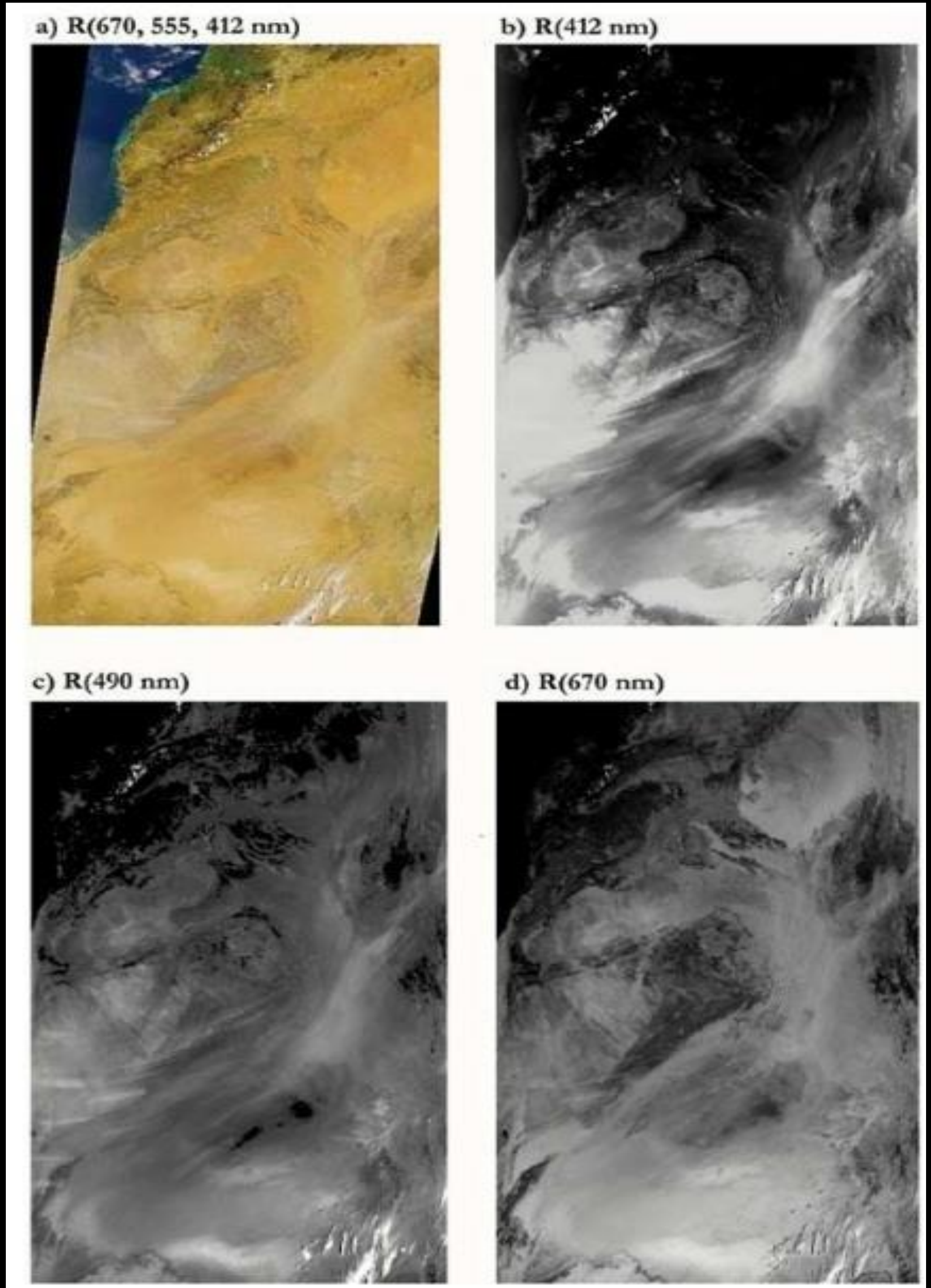
Critical Surface Reflectance

The vertical lines denote where detection of aerosols is difficult from satellite. This is because at higher surface reflectance values, it is difficult to distinguish between the underlying surface and overlying aerosol, from TOA.

MODIS Deep Blue Aerosol Algorithm over bright desert surfaces:

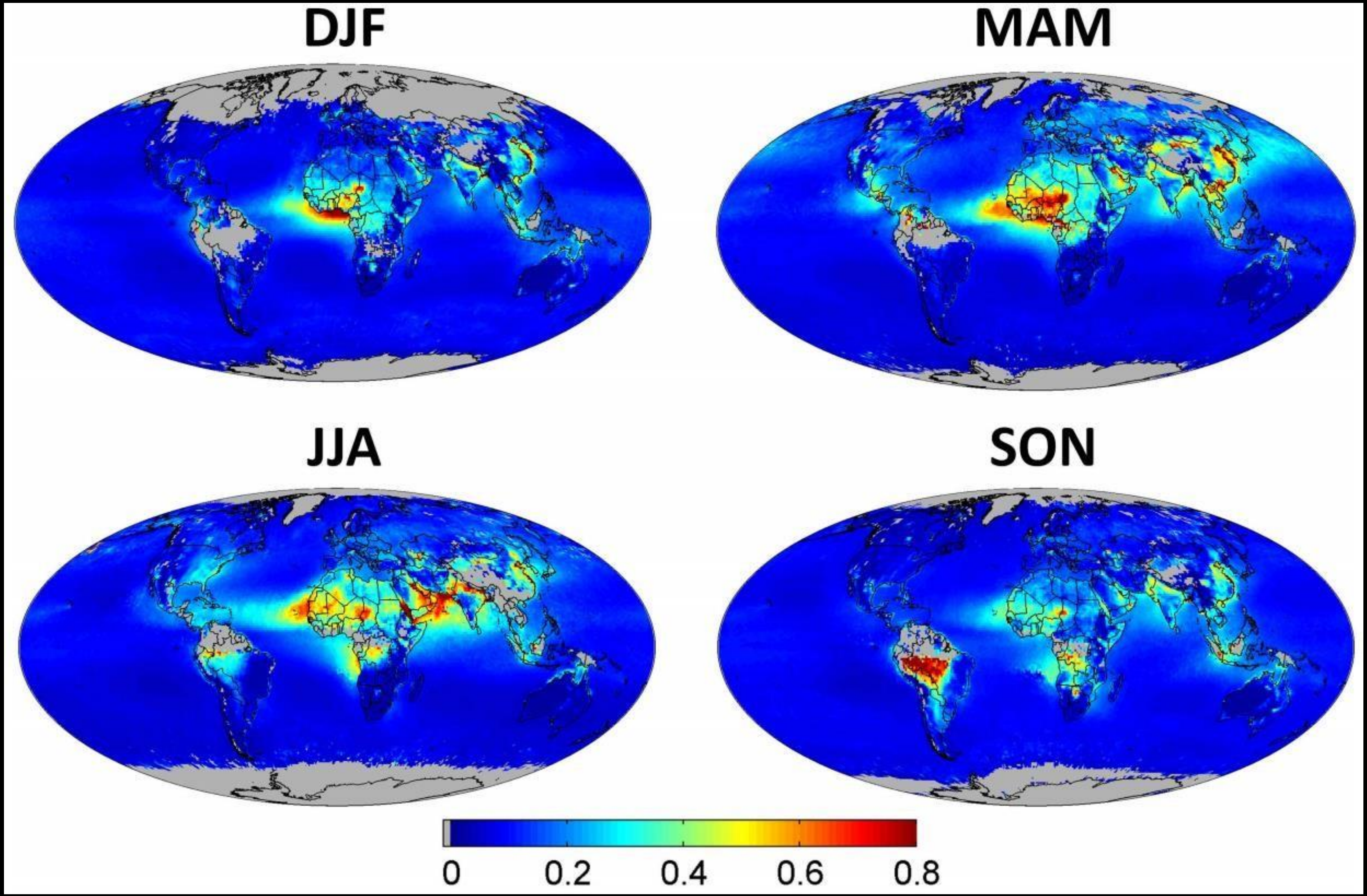
- Instead of using reflectance at 490nm and 670nm, the deep blue algorithm uses the 412nm band where desert surface appears darker. As a result, it is easier to detect aerosols over desert at deep blue band (e.g. 412nm band).





Hsu et al. 2004, TGRS

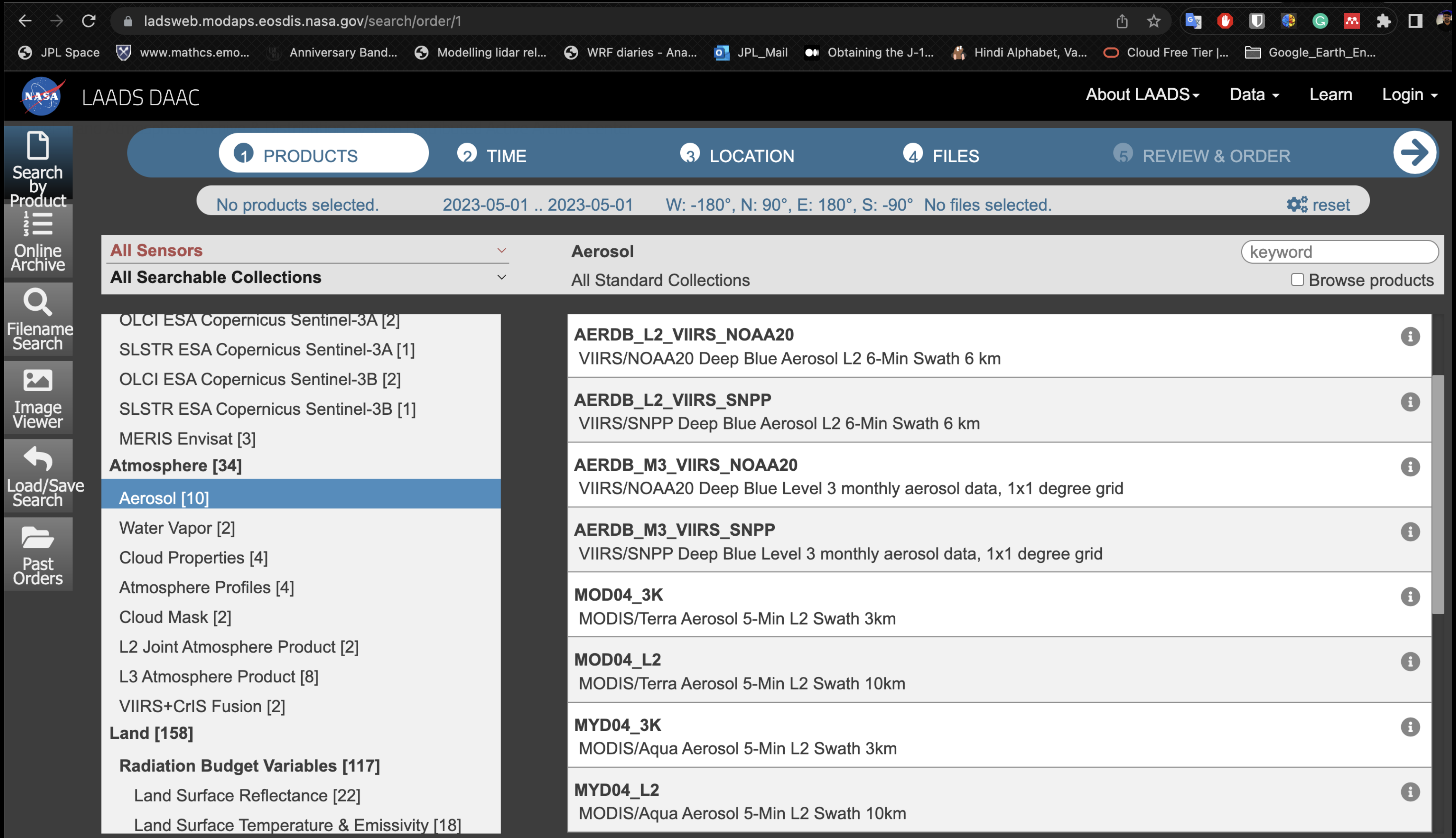
Deep Blue Aerosol Optical Depth



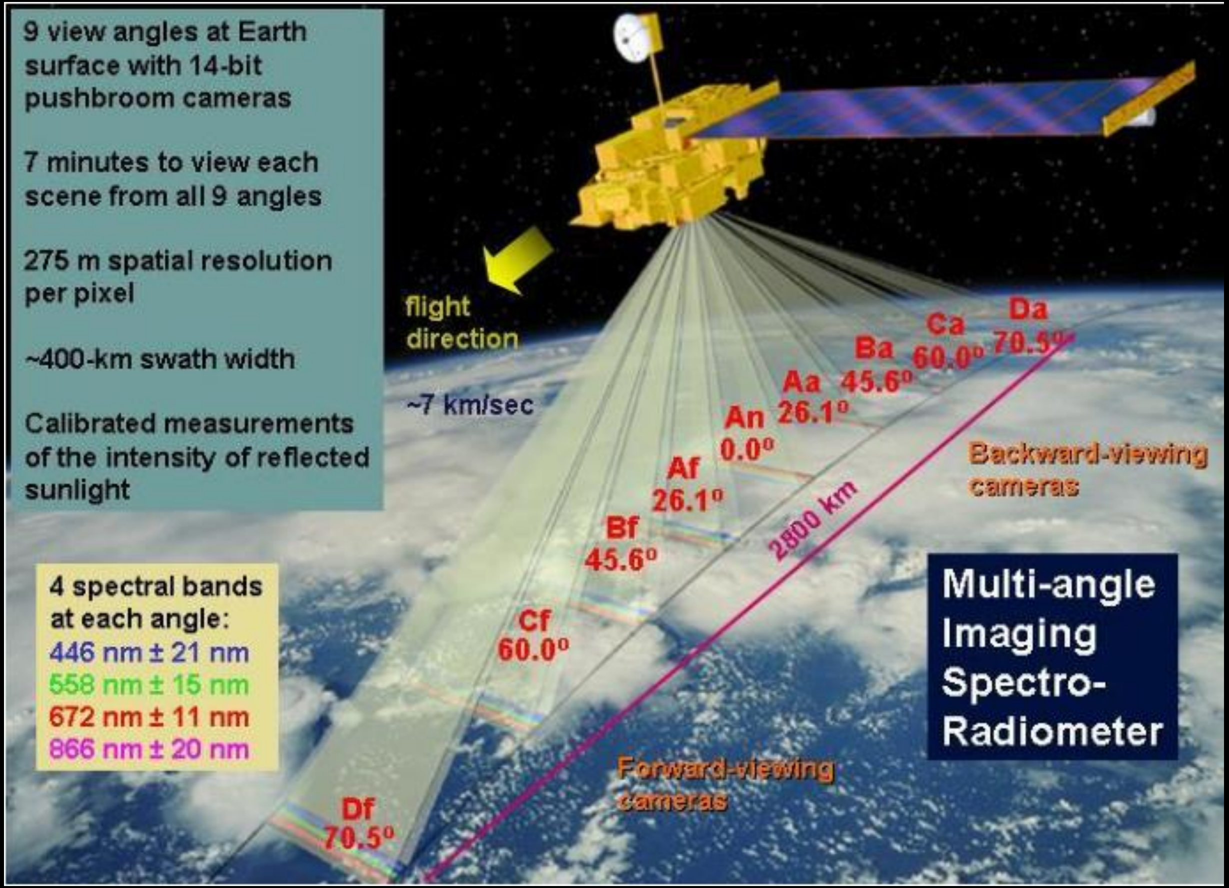
Hsu, N. C., Gautam, R., Sayer, A. M., Bettenhausen, C., Li, C., Jeong, M. J., Tsay, S.-C., and Holben, B. N.: Global and regional trends of aerosol optical depth over land and ocean using SeaWiFS measurements from 1997 to 2010, Atmos. Chem. Phys., 12, 8037-8053, doi:10.5194/acp-12-8037-2012, 2012.

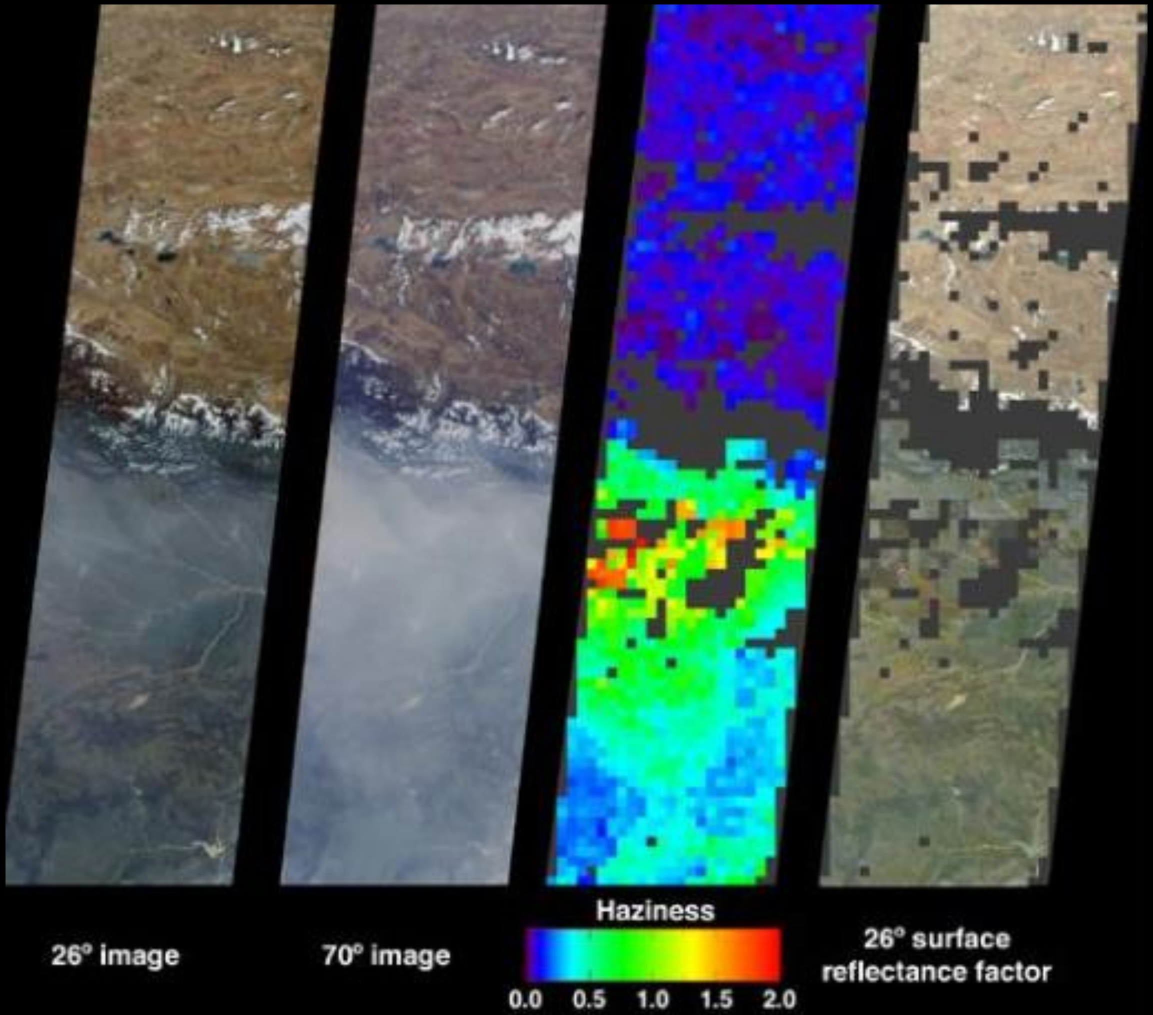
Access to MODIS & VIIRS aerosol product

(https://ladsweb.modaps.eosdis.nasa.gov/search/order/1)



Multi-angle Imaging Spectroradiometer (MISR)





Angular observations (which are not available in MODIS) makes MISR capable of providing additional information on particle size, shape and aerosol height under specific cases

The two images on left show the scene from MISR's 26-degree and 70-degree forward viewing angles, respectively. The high levels of aerosols are enhanced in the 70-degree forward image, due to the longer atmospheric path length associated with the more oblique viewing angle.

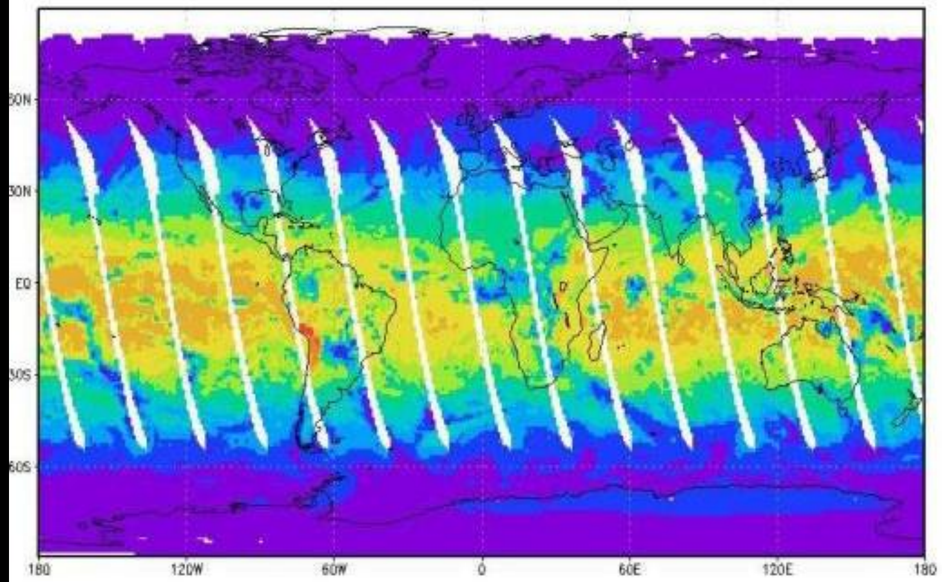
	OMI	TROPOMI
Spatial resolution	13 km x 24 km	5.5 km x 3.5 km
Aerosol products	• UV aerosol optical depth • absorbing aerosol index • Single scattering albedo • Aerosol layer height	• UV aerosol optical depth • absorbing aerosol index • Single scattering albedo • Aerosol layer height

Data access :

https://search.earthdata.nasa.gov/search

https://s5phub.copernicus.eu/dhus/#/home

Ozone Monitoring Instrument (OMI)



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

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

uses UV channels which are less sensitive to surface effects,

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

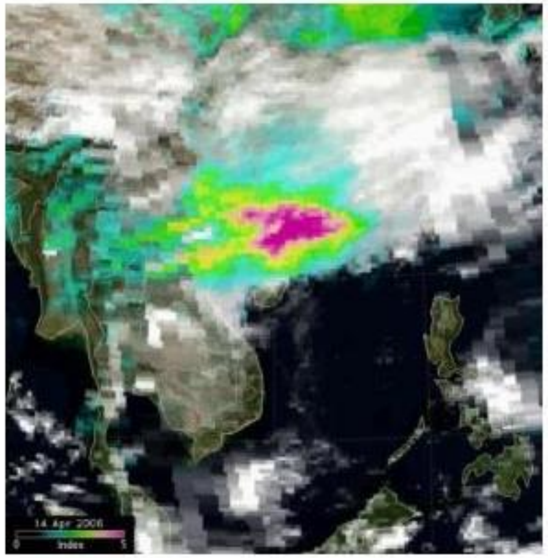
Applications of the Aerosol Index

-Validation tool for transport models

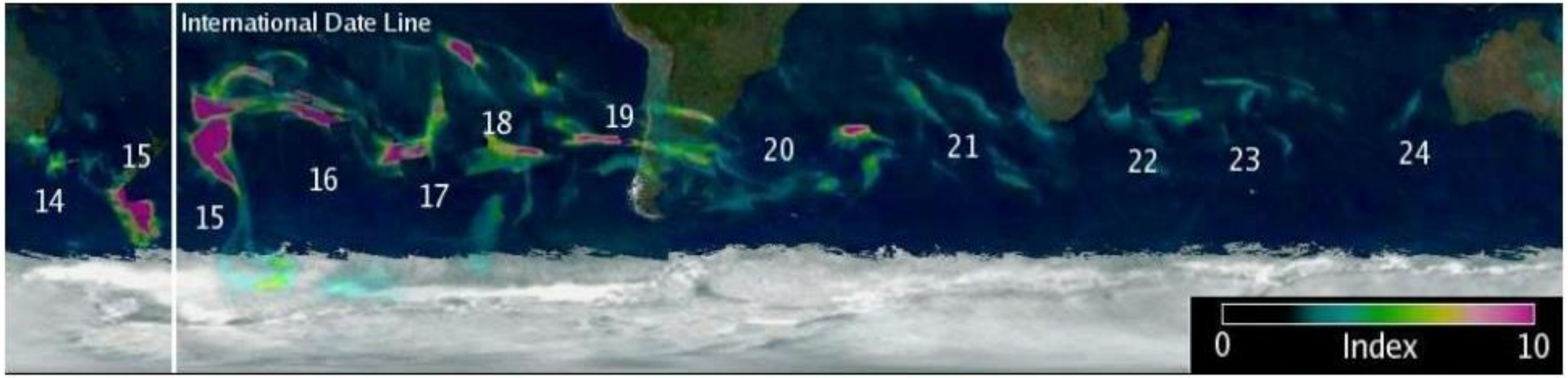
-Separation of carbonaceous from sulfate aerosols

-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



Transport around the globe of a high altitude smoke layer generated by the Australian fires in December 2006. Numbers indicate the day of the month.

Complete TROPOMI aerosol product suite:

Absorbing Aerosol Index (S5P-AAI):

- Degradation corrected in V2 (D. Stein-Zweers)
- New definitions to account for cloud effects

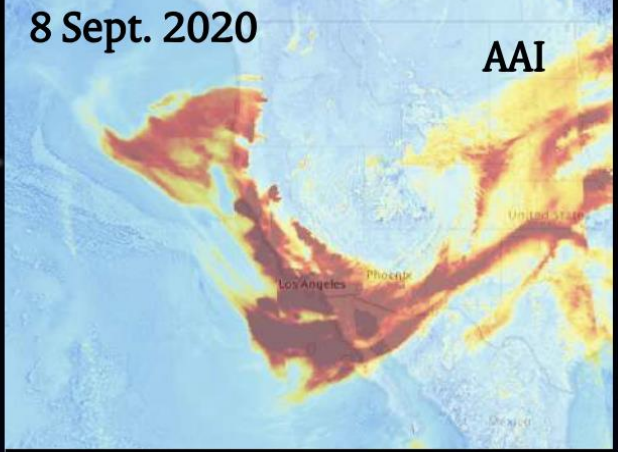
Aerosol Layer Height (S5p_ALH):

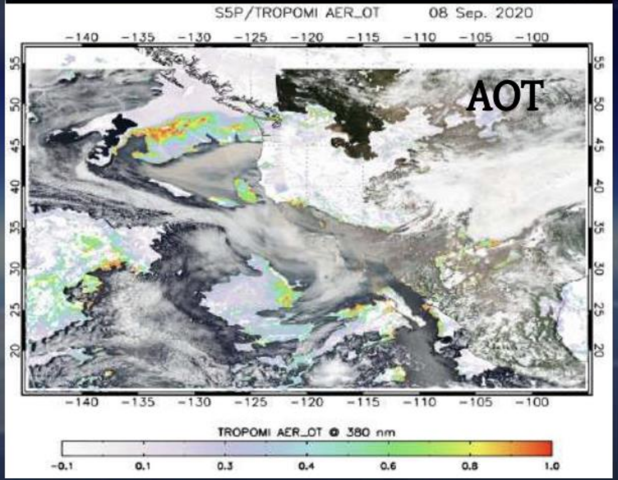
- New, fast, global operational product
- Global, based on VIIRS cloud mask
- Over land accuracy should be improved.

Aerosol Optical Thickness and Single Scattering Albedo in UV (S5p_AOT):

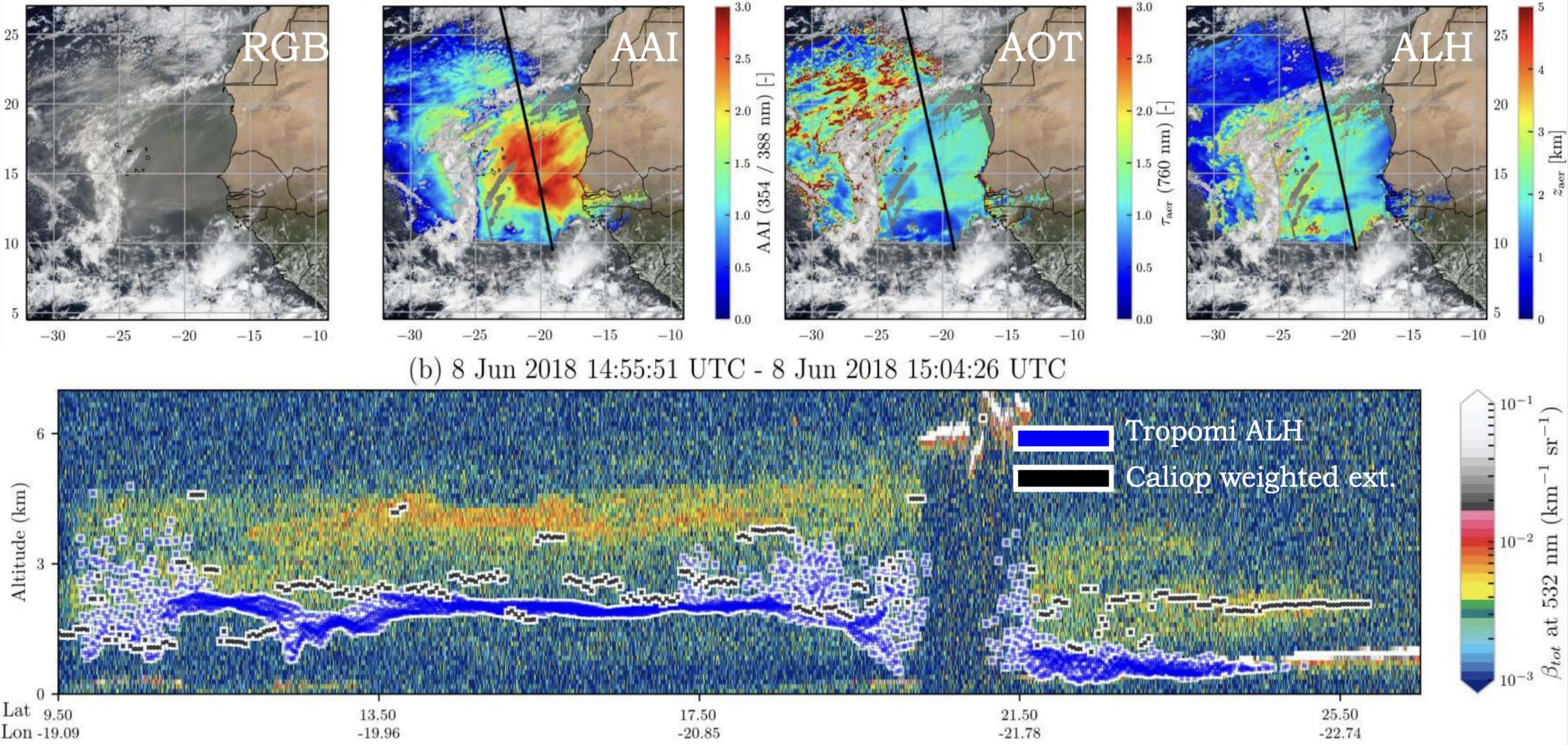
- Based on OMI OMAERO and OMAERUV algorithms in UV:
  340, 380, 416, 440, 496 nm
- Uses S5P input (CO, AAI, LER), will be improved to include
  S5P-ALH and S5P DLER
- Cloud fraction from VIIRS

All these aerosol products provide a consistent and complete view of the aerosol macrophysics and microphyics in the UV and SWIR





2018 - 06 – 08 Saharan dust

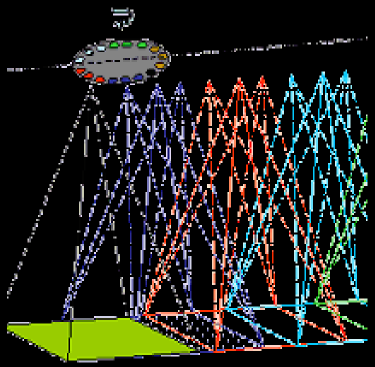


Polarimeters in Space

uses the polarization and multi-angle measurements to reduce surface effects.

2005 2013 2024 2025 2027

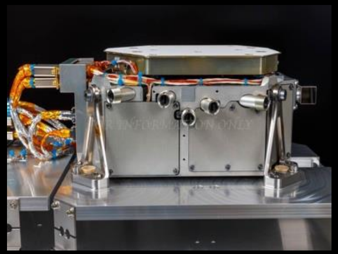
PARASOL



>10 year GAP!

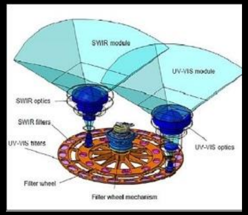
PACE

SPEXone – PACE



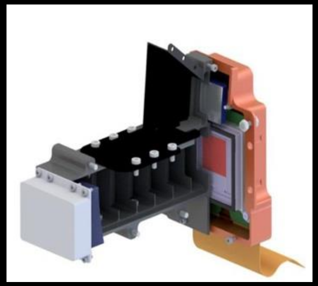
HARP2 – PACE

3MI

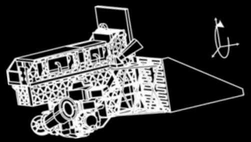


CO2M

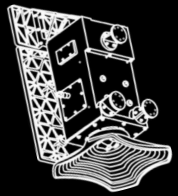
MAP



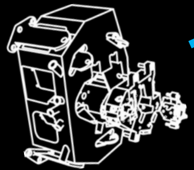
PACE Plankton, Aerosol, Cloud, ocean Ecosystem



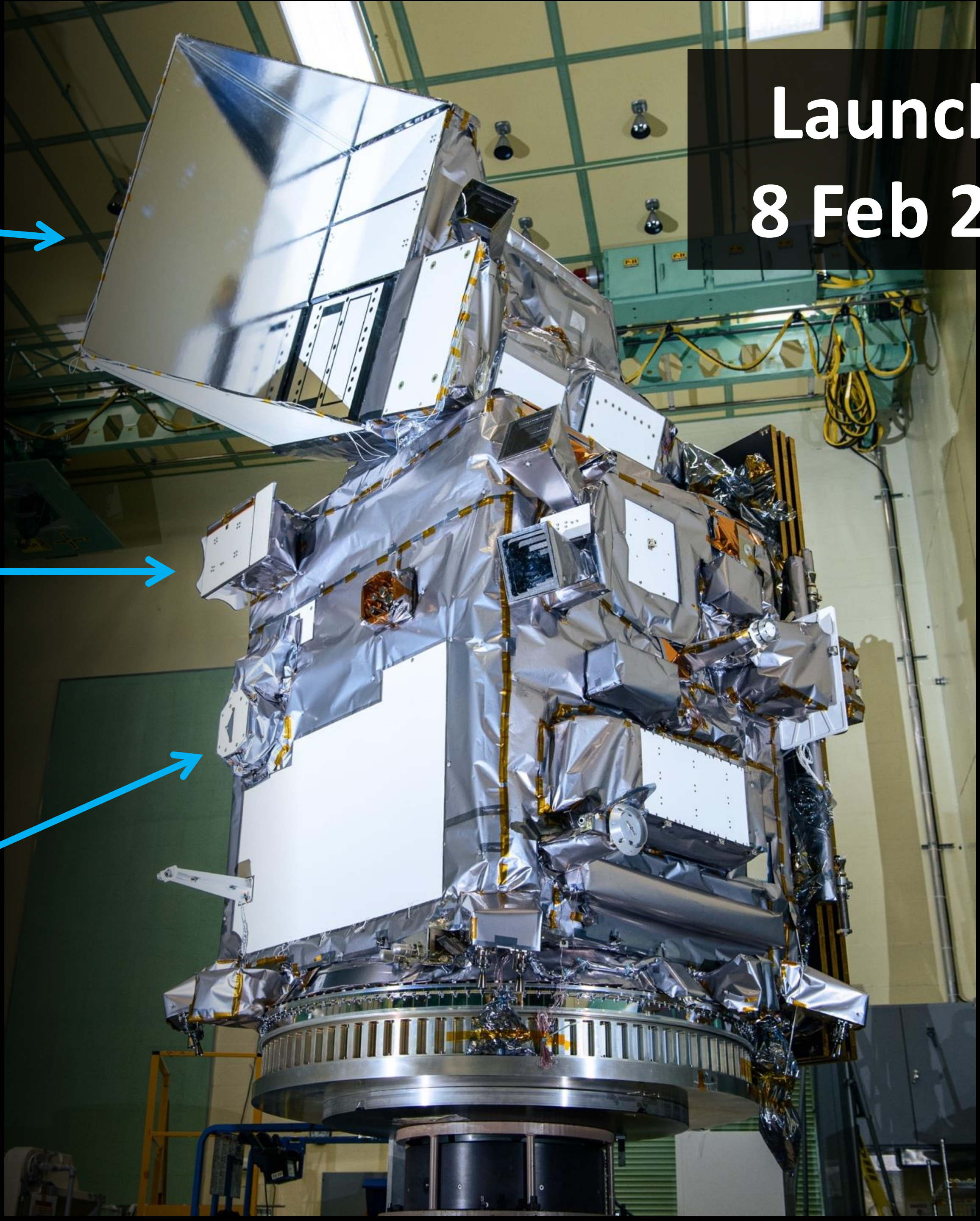
Ocean Color Imager (OCI)
UV-NIR hyperspectral: 340-890 nm in 2.5 nm steps
7 SWIR bands: 940-2260 nm
1-2 day coverage | ±20° tilt | 1km resolution



Hyper angular Rainbow Polarimeter (HARP2)
Multi-angle polarimetry in VIS 3 bands +
hyper-angular polarimetry in 1 band
10-60 viewing angles
wide swath polarimeter | 5 km resolution

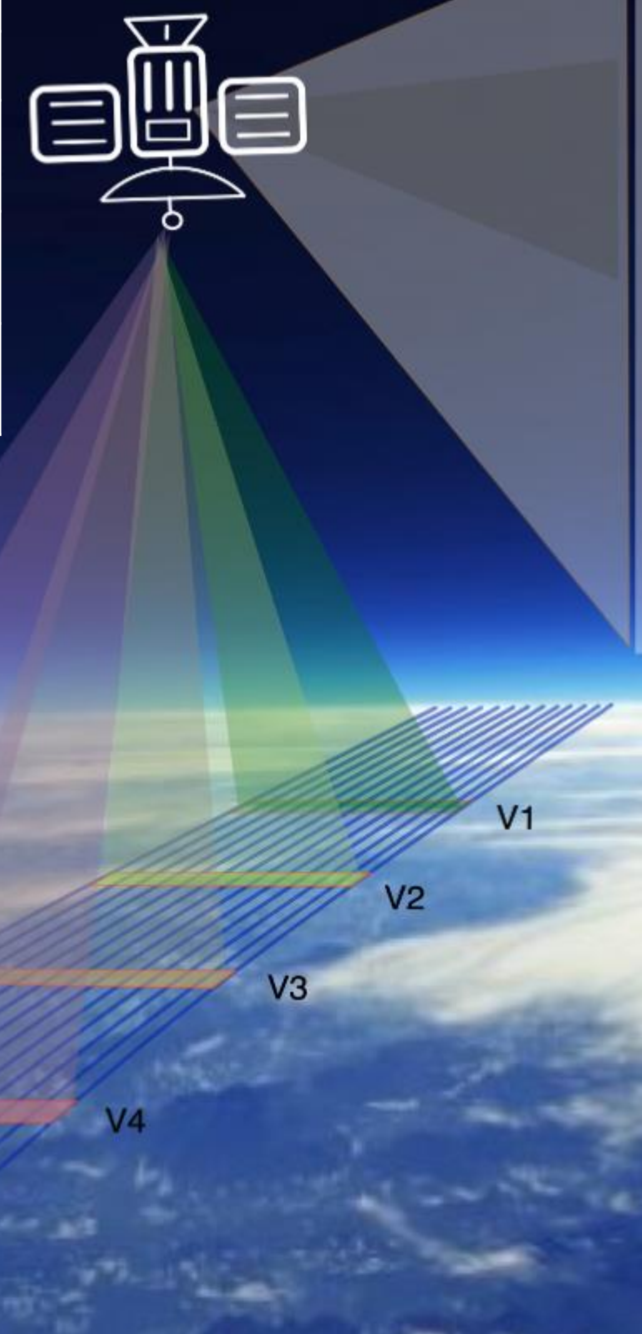


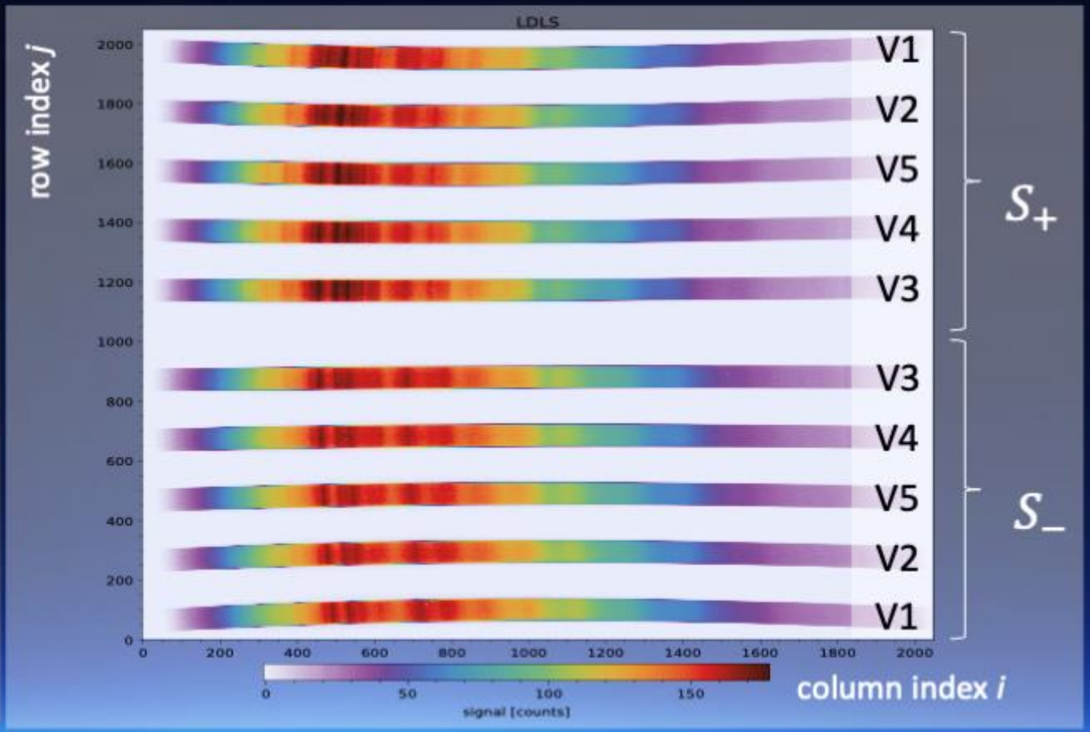
SPEXone
UV-NIR hyperspectral polarimeter : 380-770 nm
5 viewing angles | narrow swath | 5 km resolution

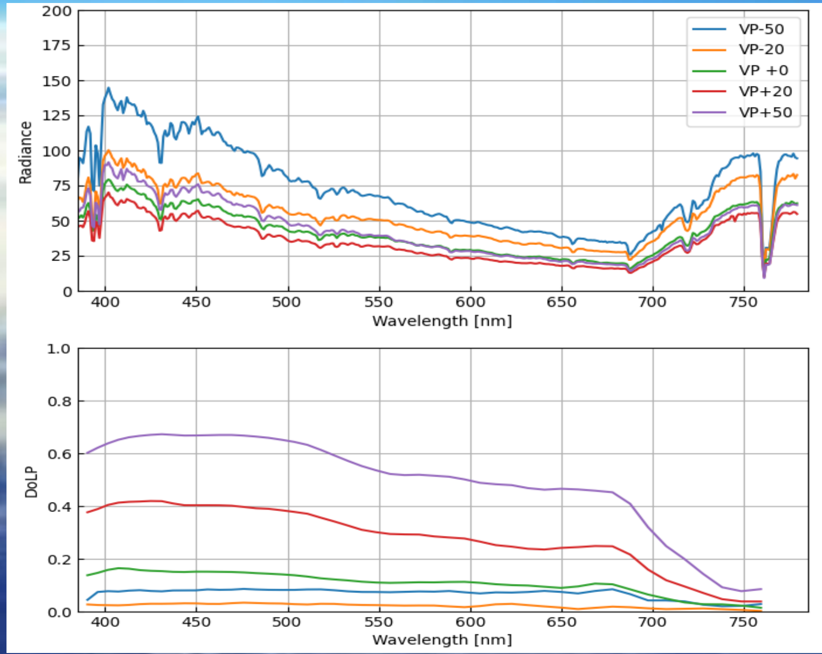


Launched 8 Feb 2024

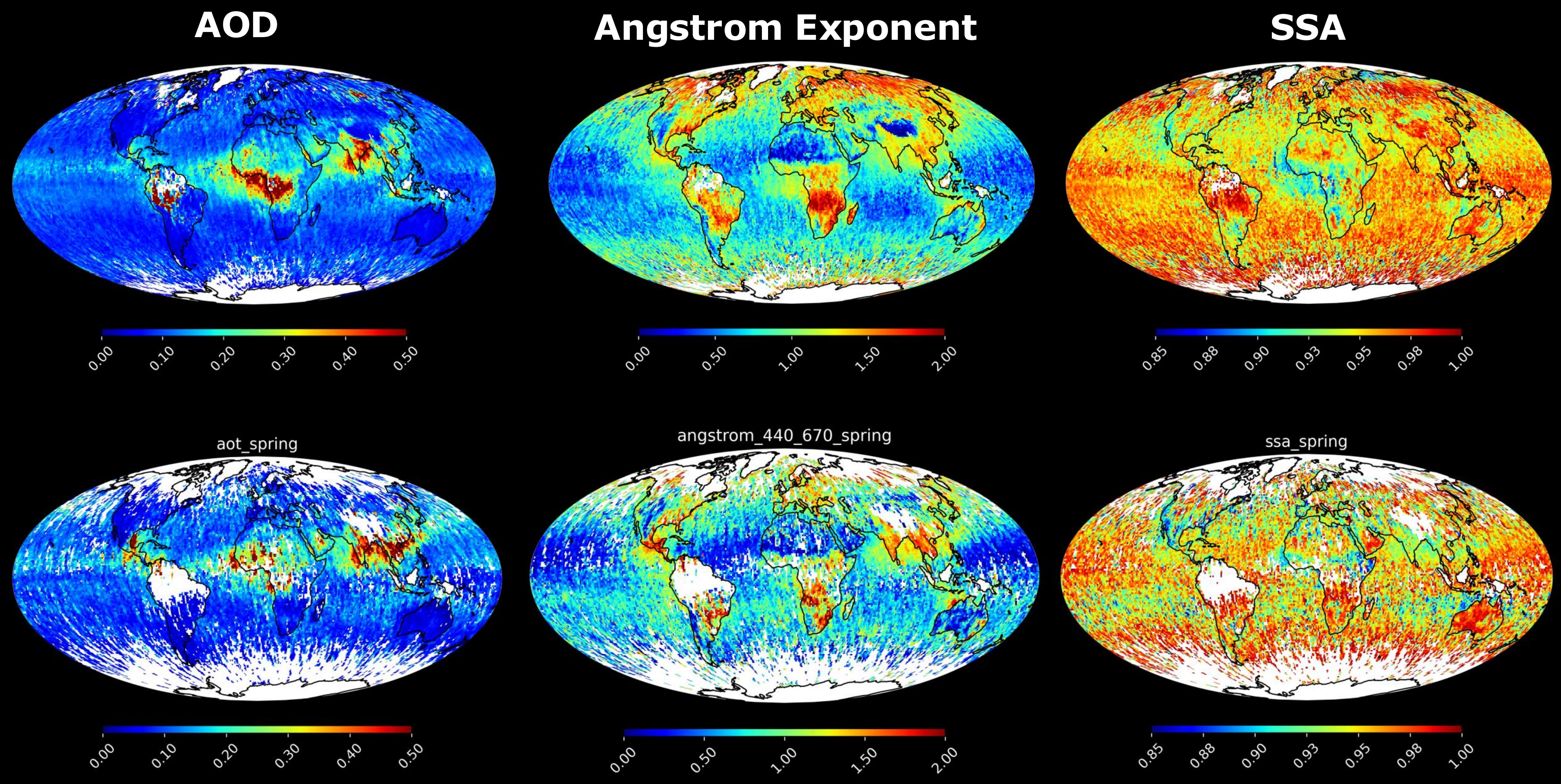
Parameter	Specification
Spatial resolution	5X5 km^2
Swath	100 km
Spectral resolution (radiance)	400 bands, 2nm FWHM
Spectral resolution (polarization)	50 bands 10-30 nm FWHM
Accuracy	2% (radiometric), 0.003 (polarimetric)







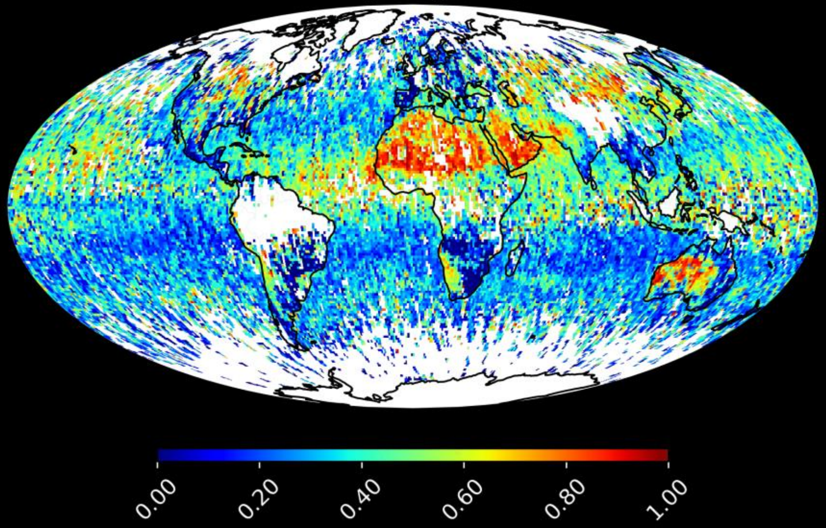
First Year of SPEXone Data: AOD, AE & SSA



Chemical Composition

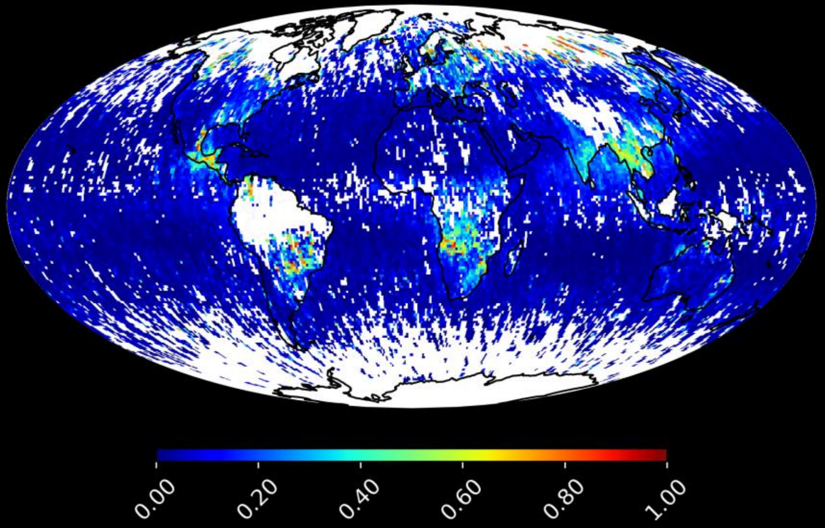
Dust

vfrac_dust_spring



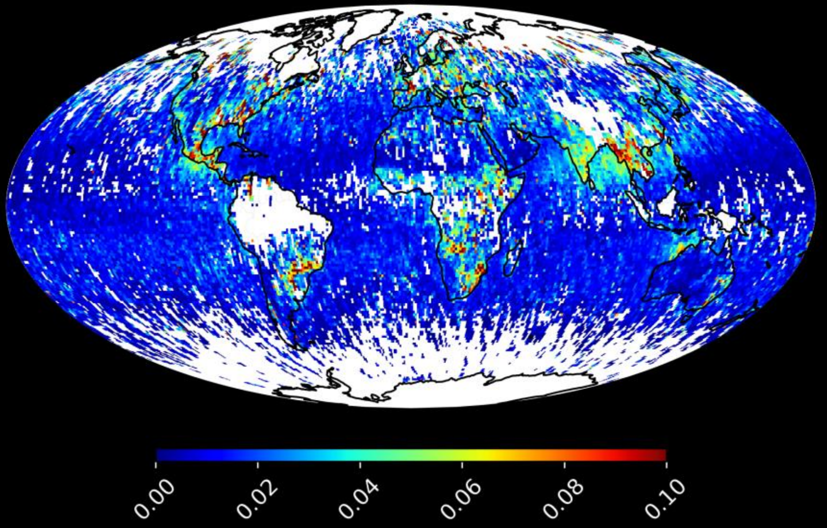
Fine mode non-absorbing

vfrac_inorg_spring



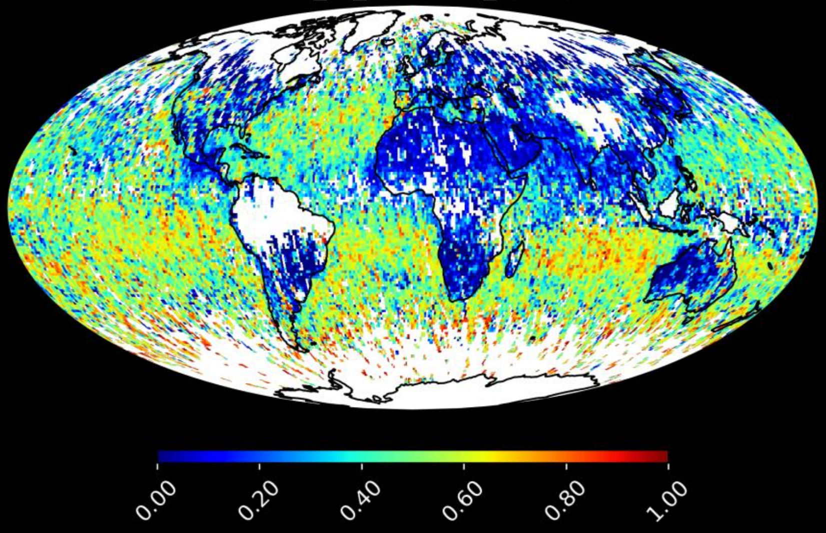
BC+BrC

vfrac_c_spring



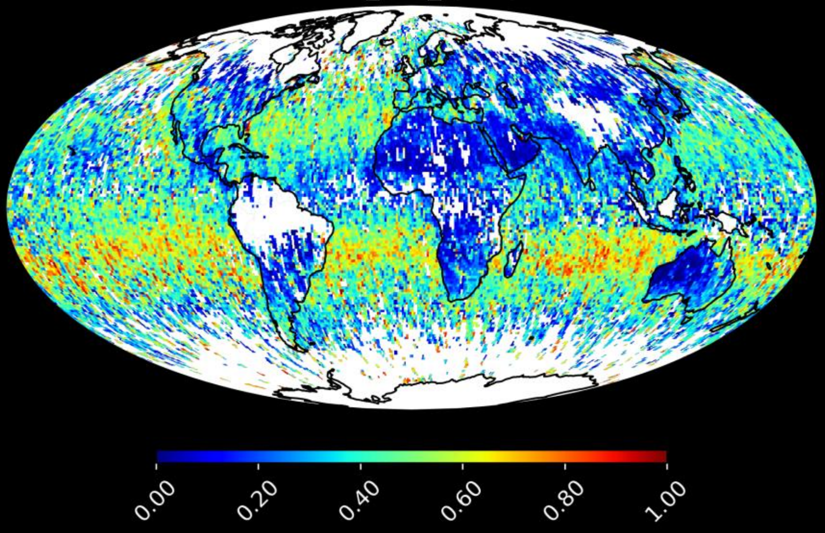
Sea Salt (hydrated)

vfrac_ss_hydrated_spring



Aerosol Water

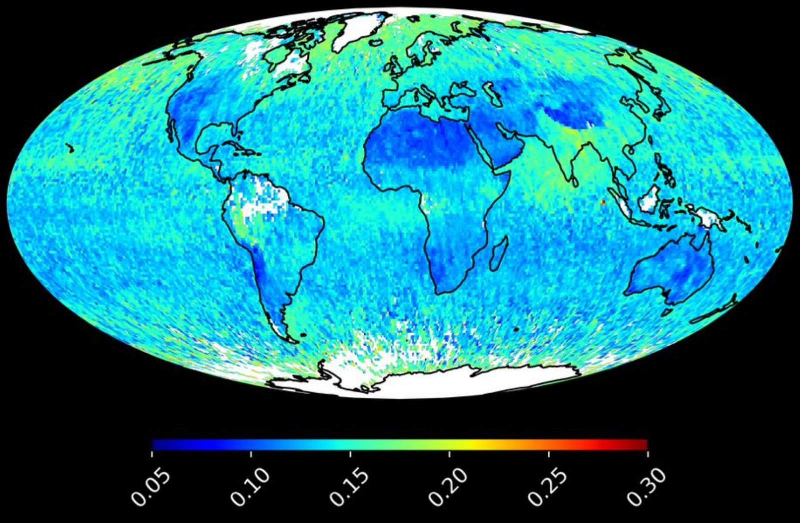
vfrac_h2o_spring



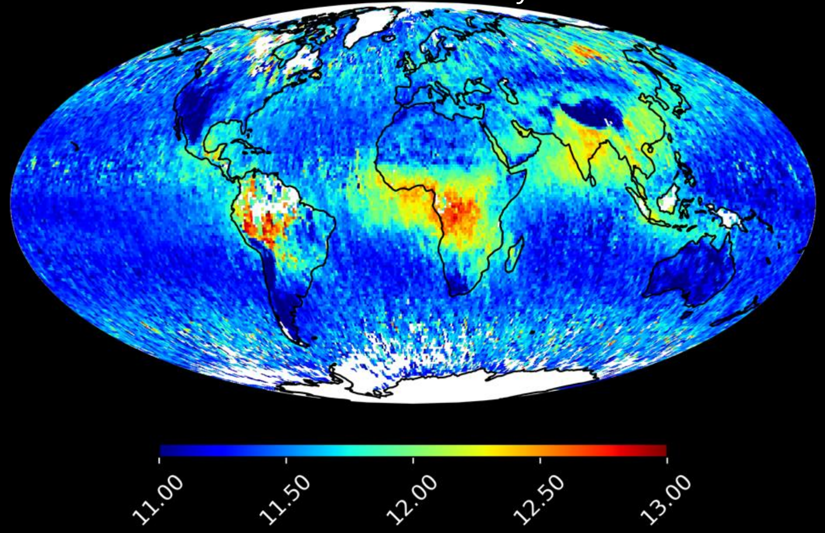
- Dust dominated close to desert (Sahara, Namibia, Australia) and outflow
- Fine mode ‘nob-absorbing’ (IA+OA) over industrial regions and BB
- Sea salt over the ocean
- Most of the sea salt contains a lot of water. Small water fraction over most of land
- BC+BrC over dominates Africa

Size, refractive index, and CCN proxies

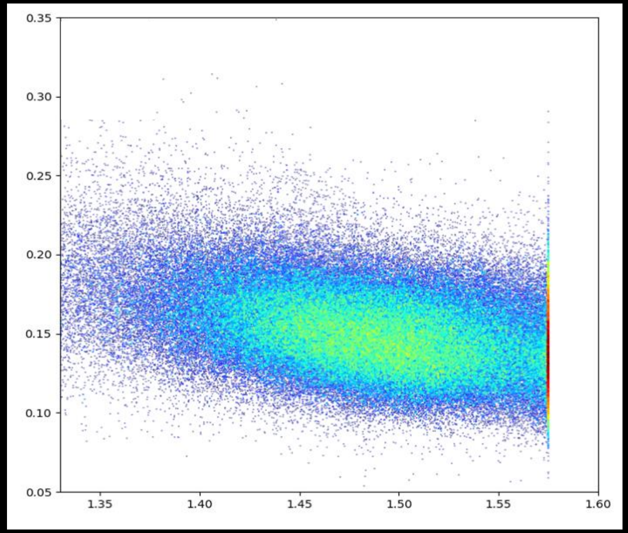
Fine mode effective radius (μm)



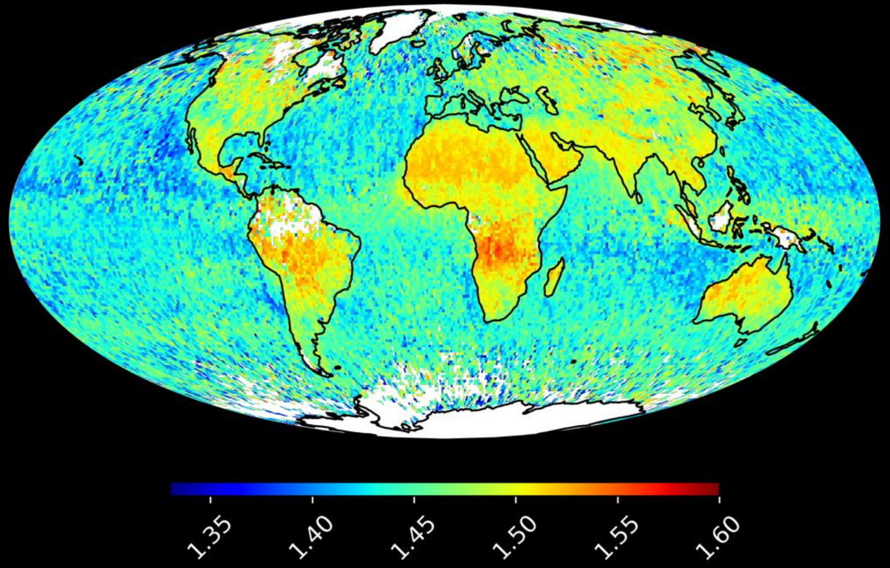
(Log of) Particle column r_{dry} > 0.10 micron



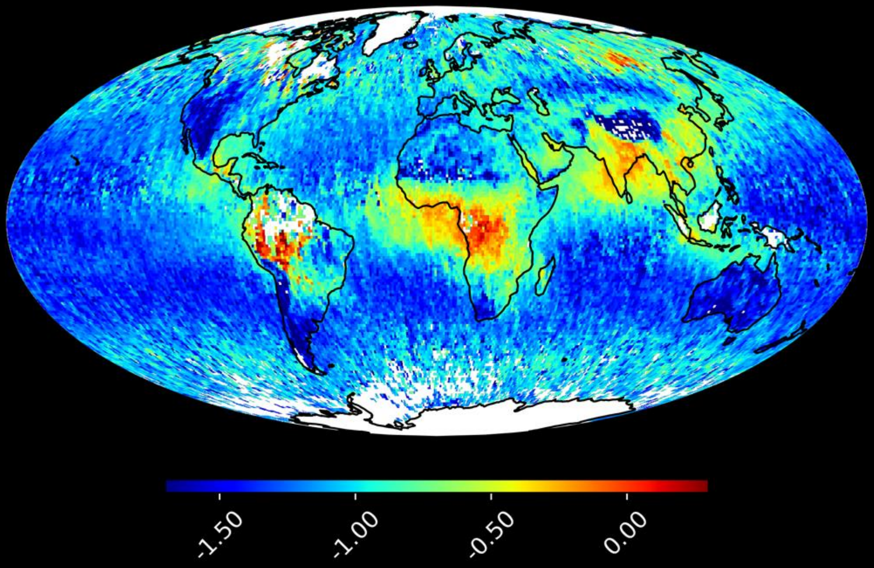
Reff vs RRI (global)



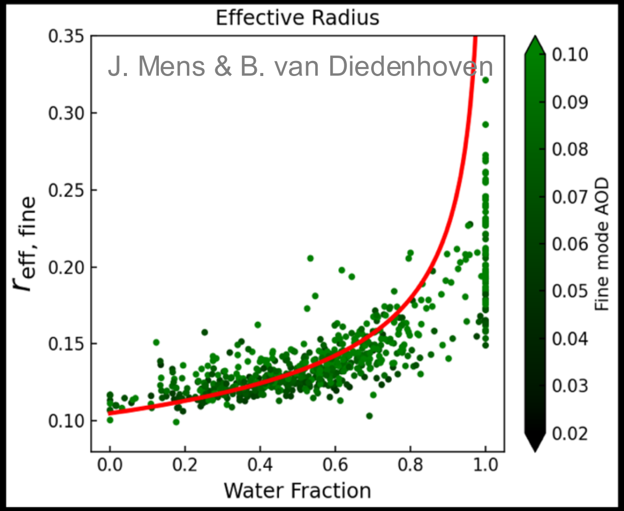
RRI



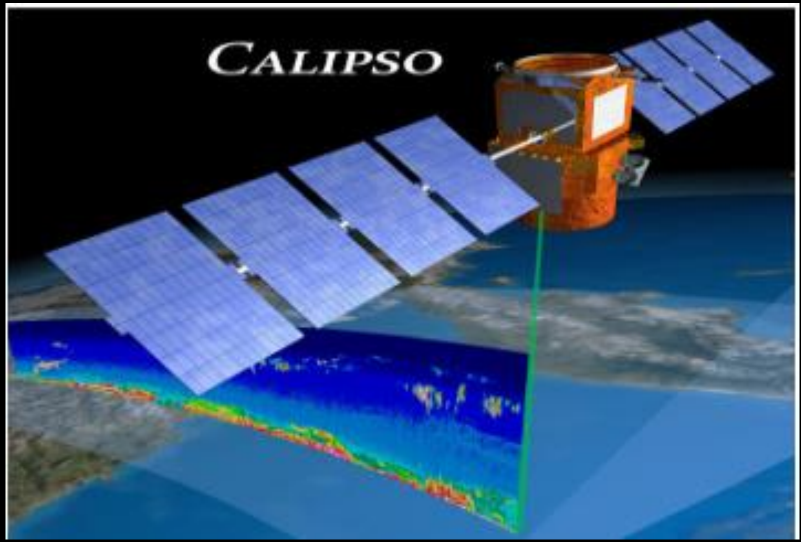
(log of) AI



Reff vs water fraction (granule)



CALIOP- CALIPSO : 2006 -2023



Launch date: April 28, 2006
Mission duration: 15+ years …

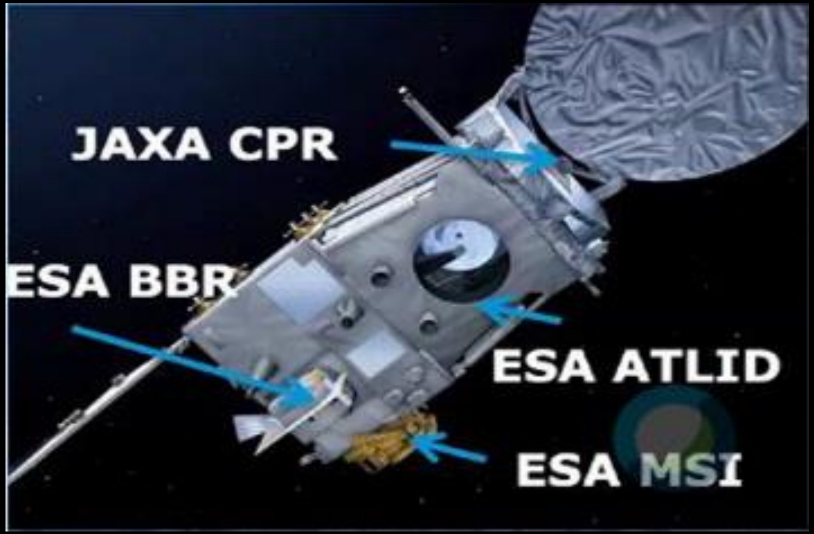
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) backscatter lidar that provides high-resolution vertical profiles of aerosols and clouds

a two-wavelength lidar system (532 nm and 1064 nm)

spatial resolution: 333 m

vertical resolution: 30 m

ATLID-EarthCARE



Launch date: May 28, 2024
Mission duration: 3+ years …

Payload: 2 active (ATLID & CPR), 2 passive (BBR & MSI) instruments

ATmospheric LIDar (ATLID) – UV HSRL lidar with depolarization providing high resolution profiles of aerosols

a single wavelength lidar system (355 nm)

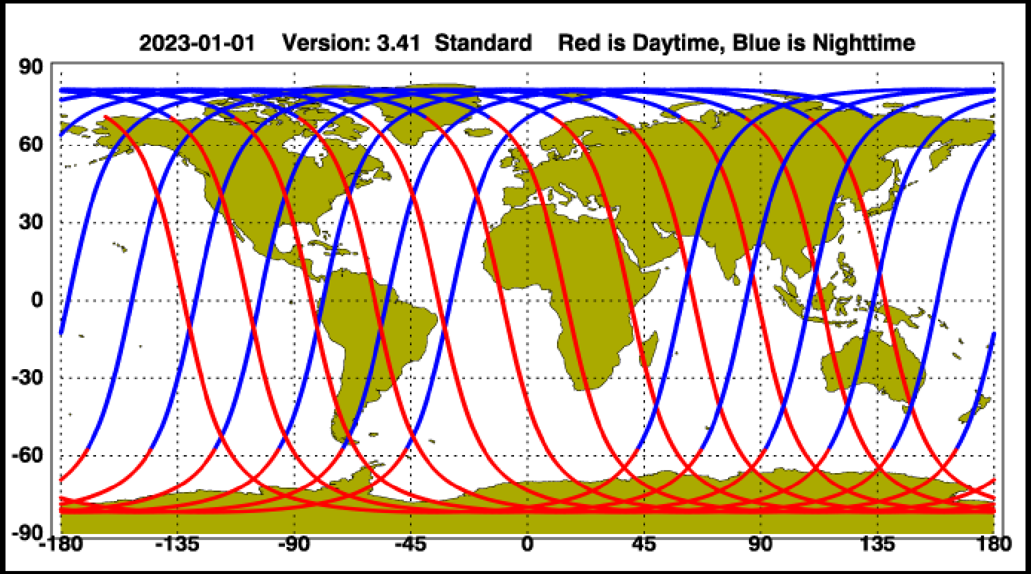
spatial resolution: 285 m

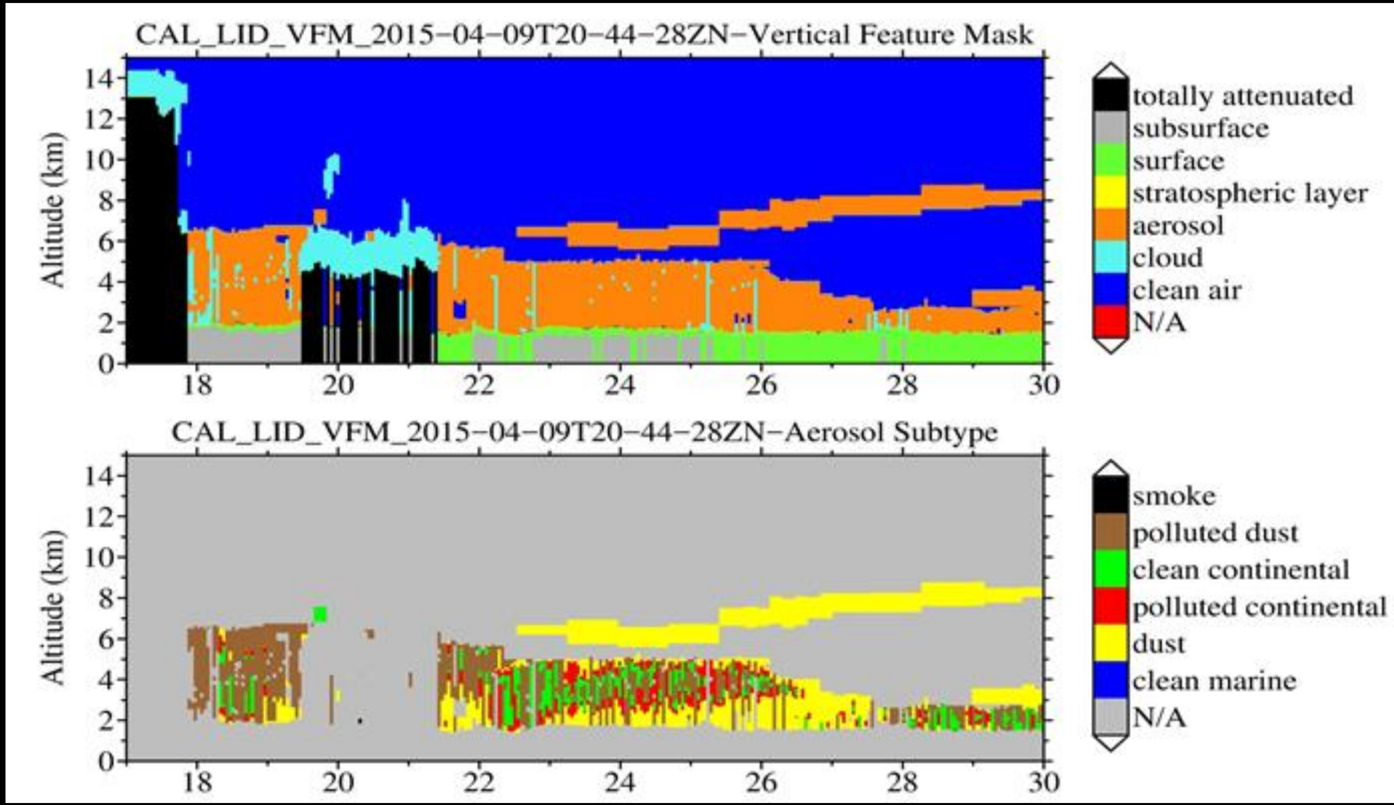
vertical resolution: 03 m (up to 20 km), 500 m (20-40 km)

Aerosol Variables from Lidar

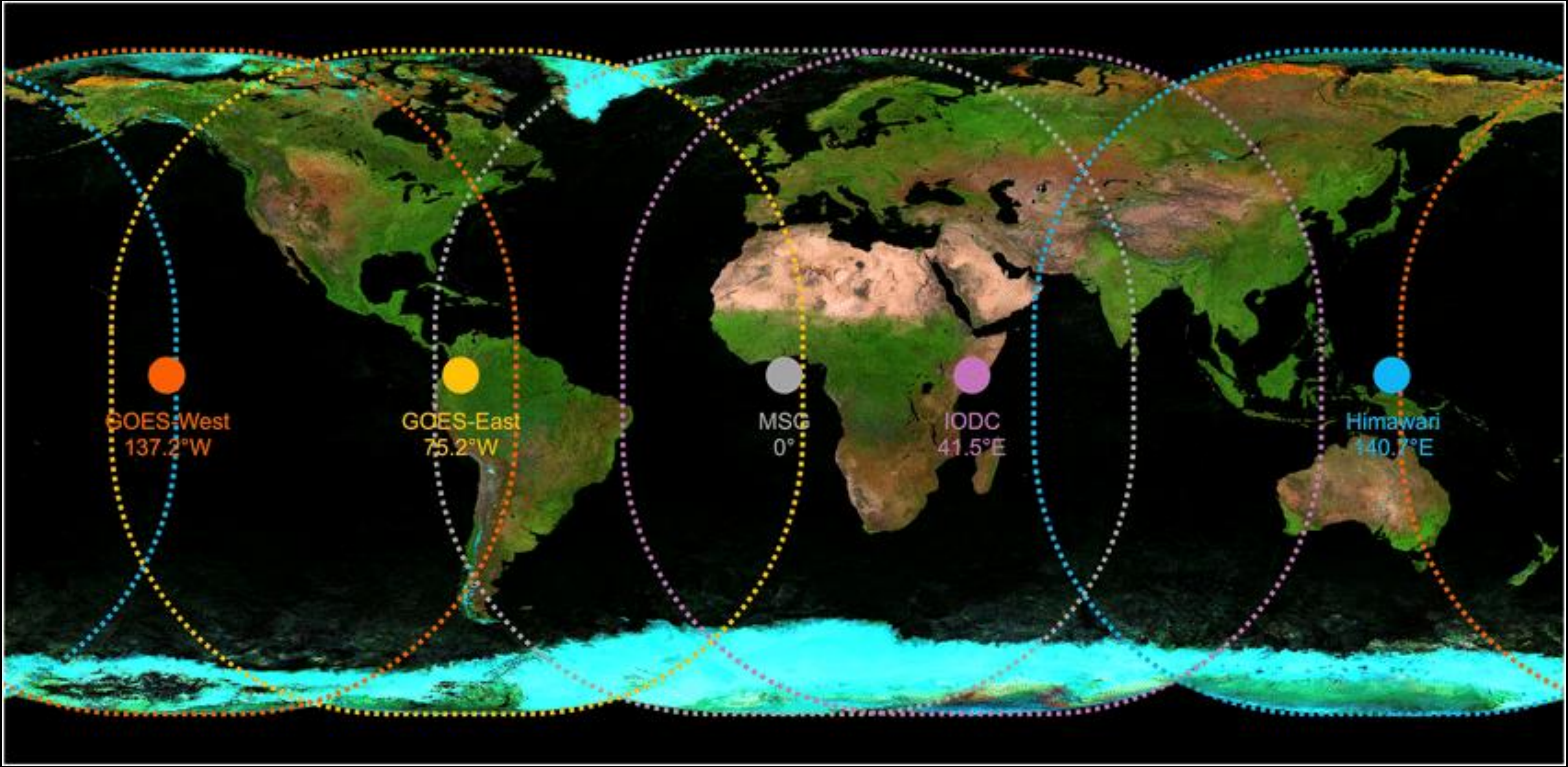
- Backscatter Coefficients
- Extinction Coefficients
- Color Ratio
- Depolarization Ratio

- Vertical Feature Mask
- Aerosol Type
- Cloud Type





Geostationary Satellites




Thank you for patience