Satellite Remote Sensing of Aerosol

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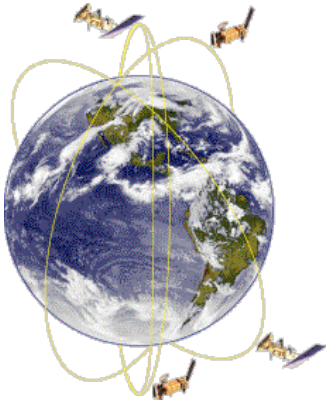
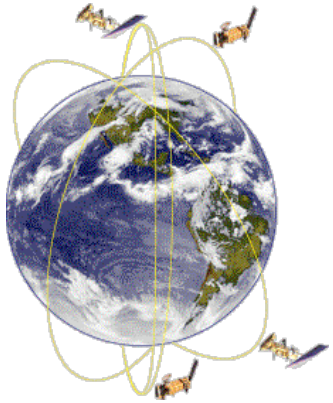




Presented at
Workshop on Aerosol-Climate Interactions: Mechanisms, Monitoring, and Impact in Tropical Regions
11-15 February 2008
Hurghada, Egypt

CONTENTS OF THE PRESENTATION

1. Definitions of Aerosol Parameters and their use in Models

Definitions:

Optical depth (τ): a measure of transparency: the fraction of radiation scattered or absorbed on a path (extinction optical depth)

$$e^{-\tau} = I / I_0$$

I_0 is the radiation intensity at the source and I is the radiation received at the sensor along the vertical path

◊ determines the amount of radiation removed from a beam by scattering and absorption during its path through a medium.

$$e^{-\tau / \cos\theta} = I / I_0$$

If the path from the source to the sensor is at a slant angle θ

$\tau = 0$ ◊ the path is fully transparent (no radiation is removed)

$\tau >> 0$ ◊ the path is opaque (all radiation is absorbed or scattered)

Single Scattering Albedo (SSA):

$$\text{AOD} \equiv \tau = \underbrace{\tau_{sc}}_{\text{scattered}} + \underbrace{\tau_{abs}}_{\text{absorbed}}$$

τ_{sc} & τ_{abs} are optical depths due to scattering and absorption, respectively

$$SSA \equiv \omega_0 = \frac{\tau_{SC}}{\tau}$$

** Can be determined, for example, from a combination of MODIS and TOMS (UV) data*

◊ SSA measure of the effectiveness of scattering relative to extinction

◊ Range 0 to 1.0: high values indicate either high scattering values or low absorption values

◊ Variations in SSA are driven by the type of aerosol:

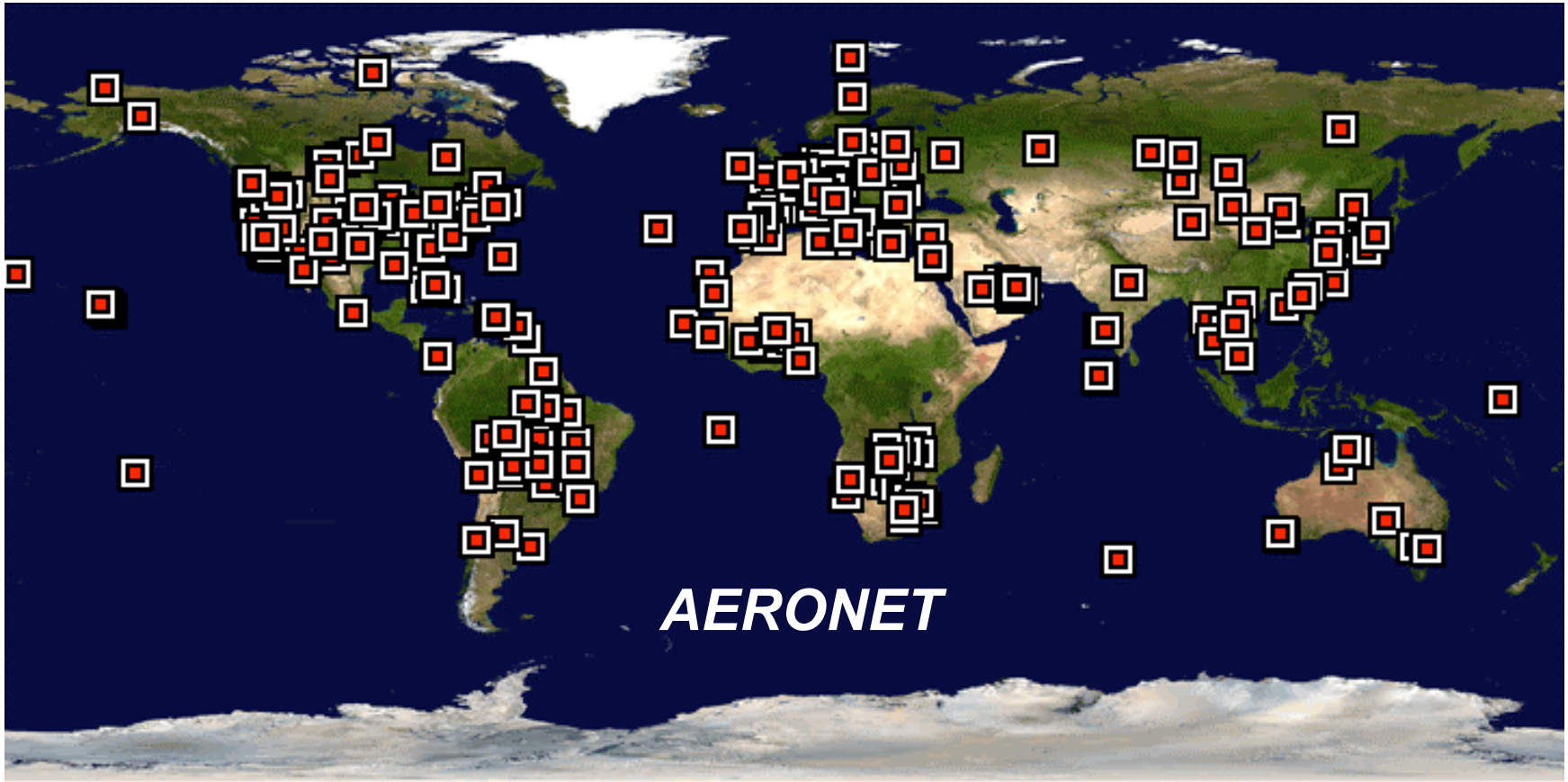
<u>In the VIS spectral regions</u>
pure sulfates in a high humidity environment has a large SSA (~ 0.98 to 0.99)
biomass burning aerosols containing a relatively high proportion of carbonaceous has a relatively low SSA (~ 0.9).

2. Ground Measurement of Aerosol (AERONET)

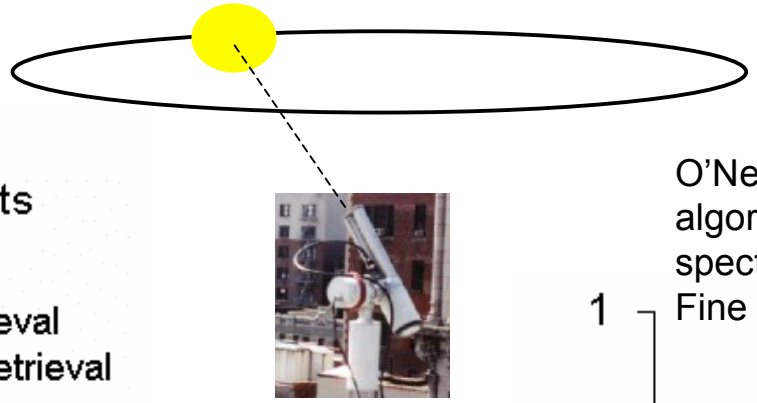
AERONET

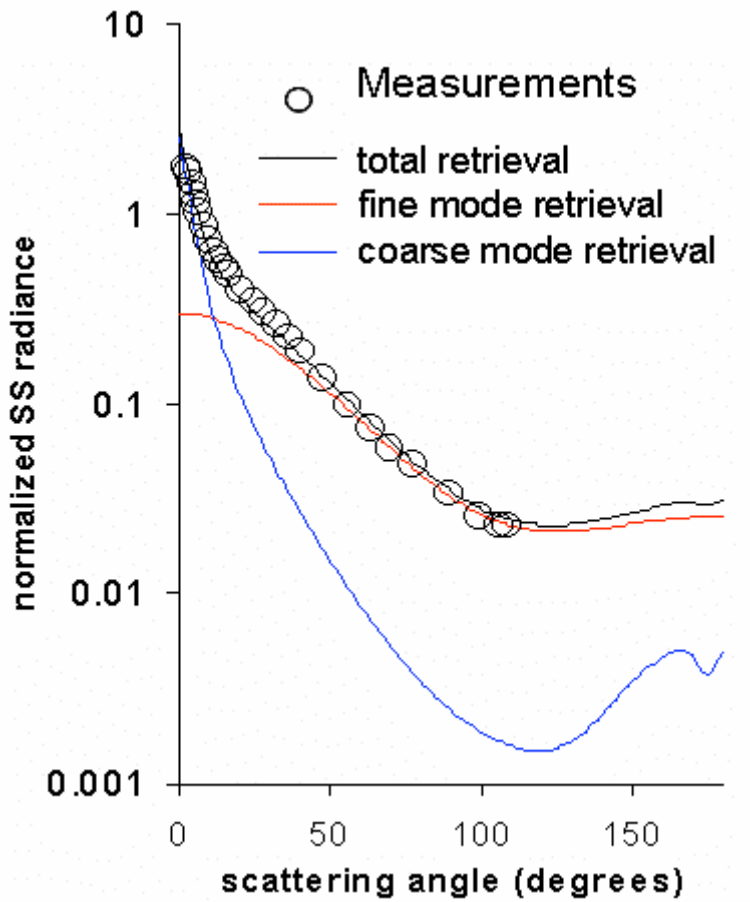
(**AE**rosol **RO**botic **NET**work) program is a federation of ground-based remote sensing aerosol networks established

AERONET data set is a key for validation of satellite RS retrieval algorithms!

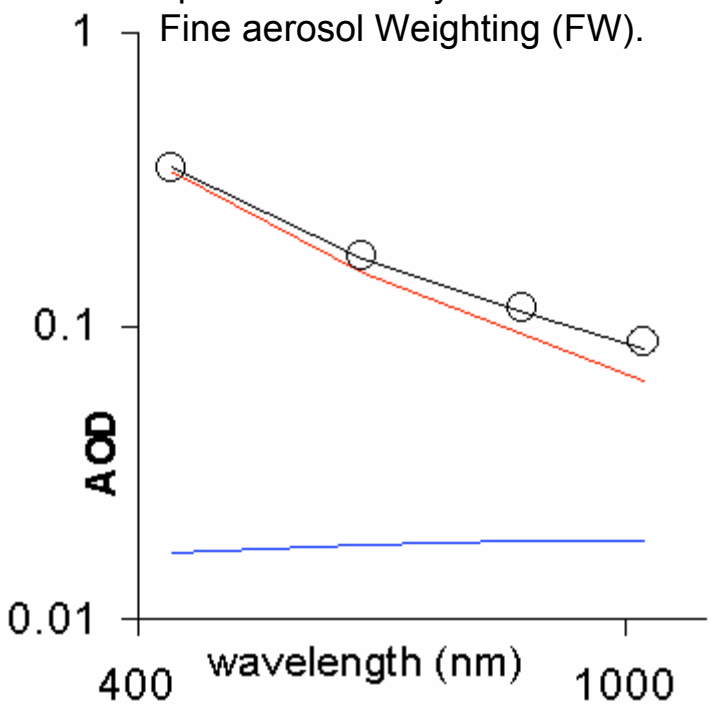


Data inversion (sunphotometry & sky radiometry)



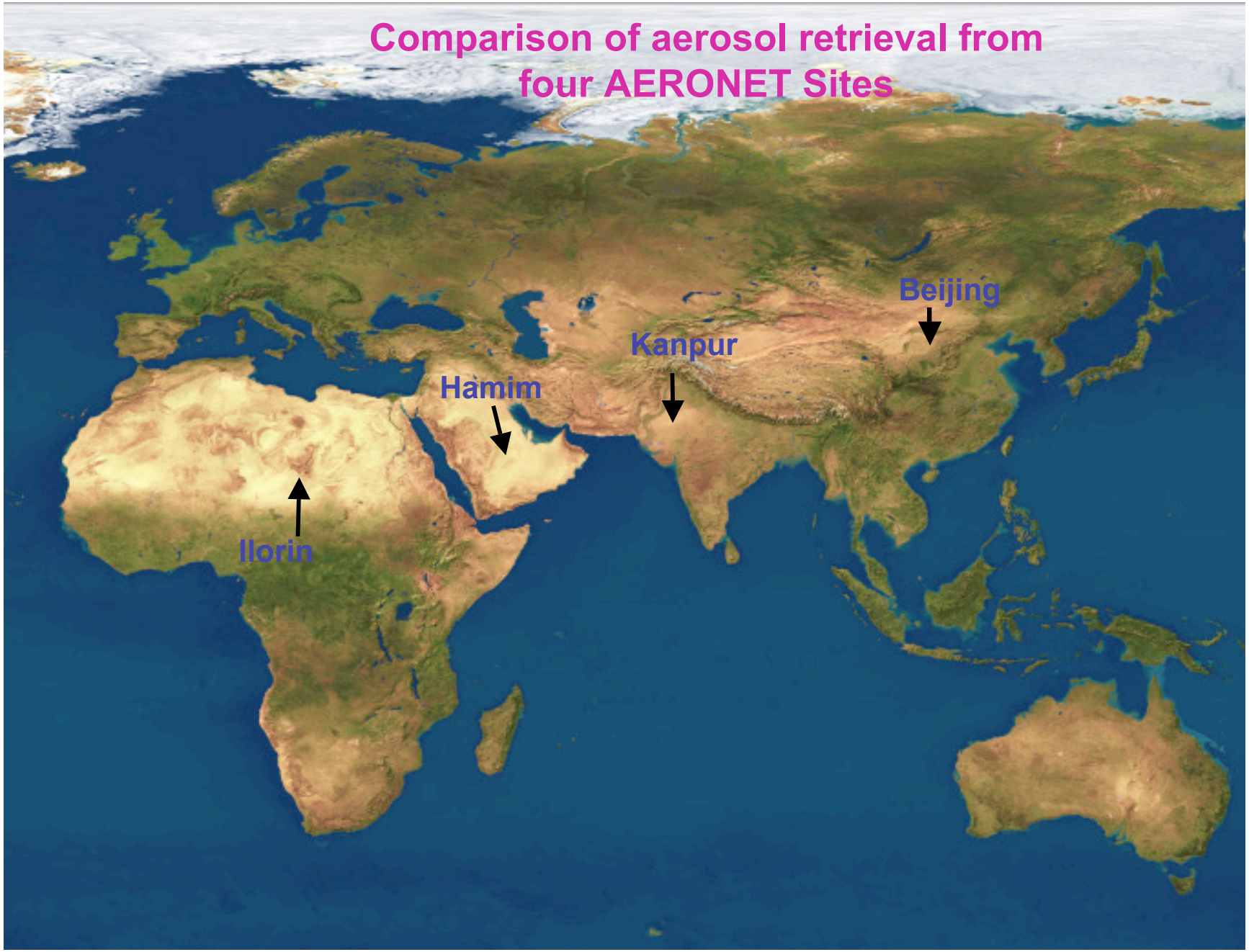


O'Neill et al., (2003) developed an algorithm to invert sun-measured spectral AOD to yield estimates of Fine aerosol Weighting (FW).



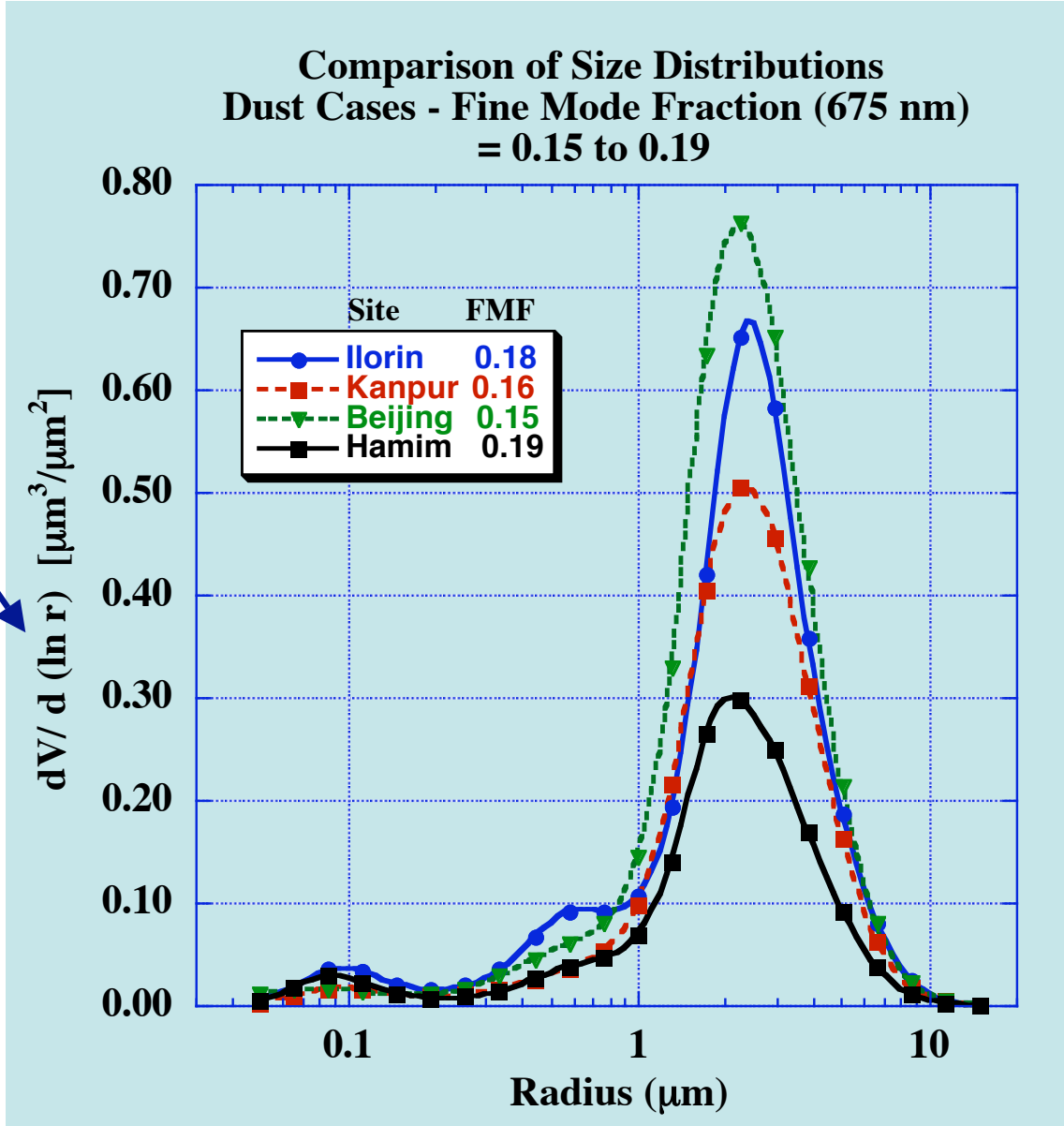
A valid MODIS/ AERONET match is considered. About 136,000 individual AERONET sky retrievals were used to develop the global/ seasonal aerosol climatology, which is used in the C005-L retrieval algorithm

Comparison of aerosol retrieval from four AERONET Sites



AERONET inversion
Comparison of aerosol from 4 AERONET sites

This represents aerosol concentration



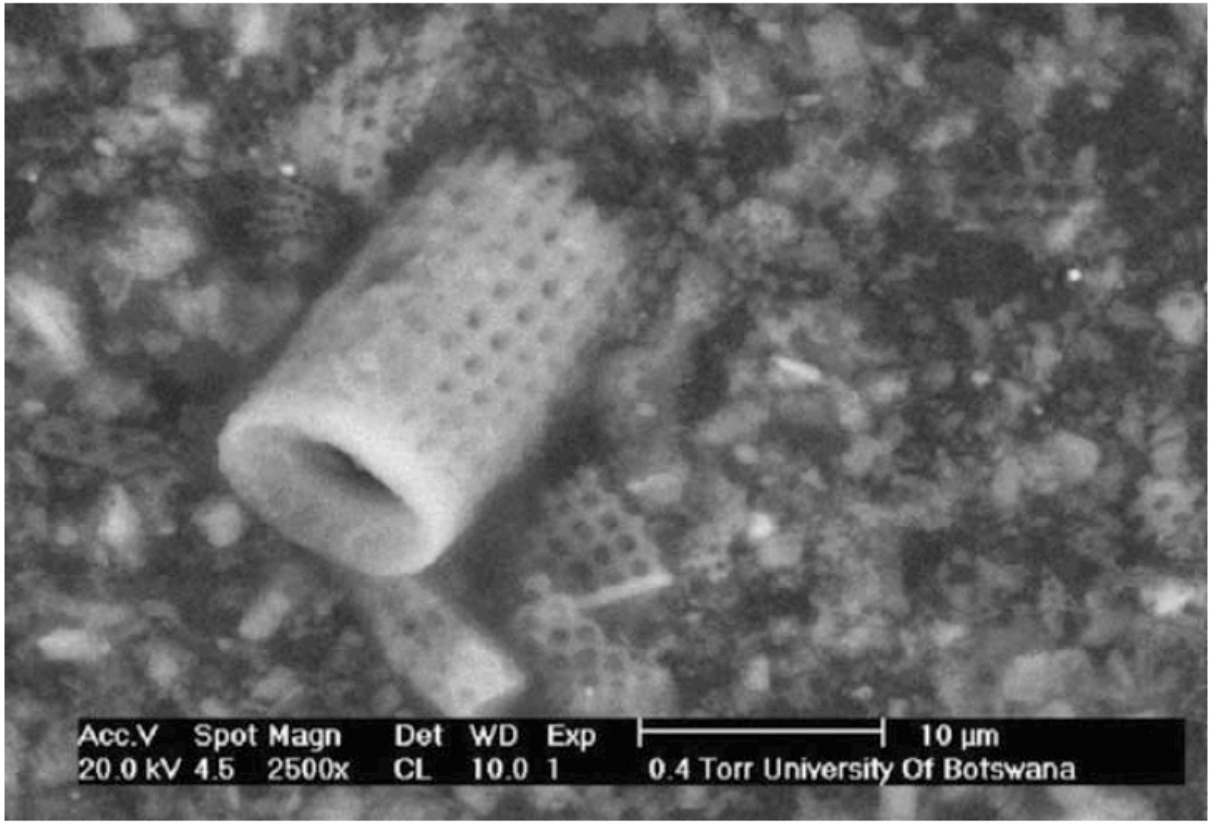
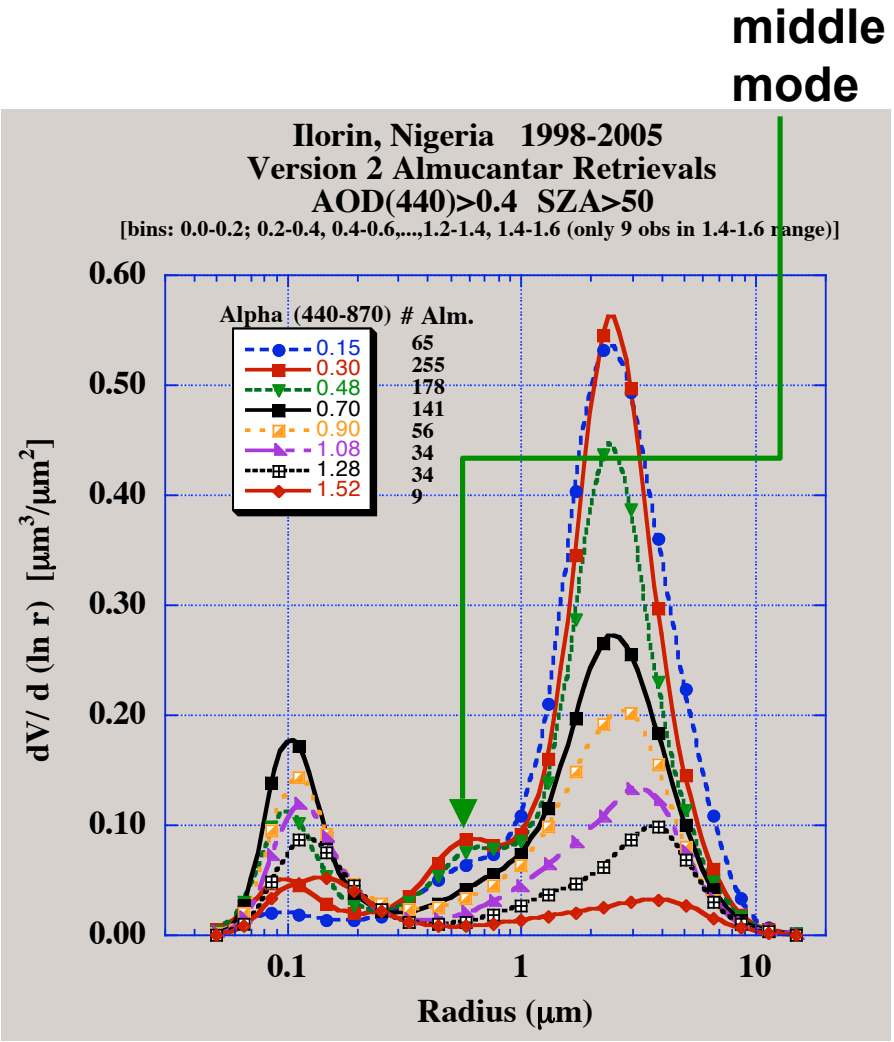


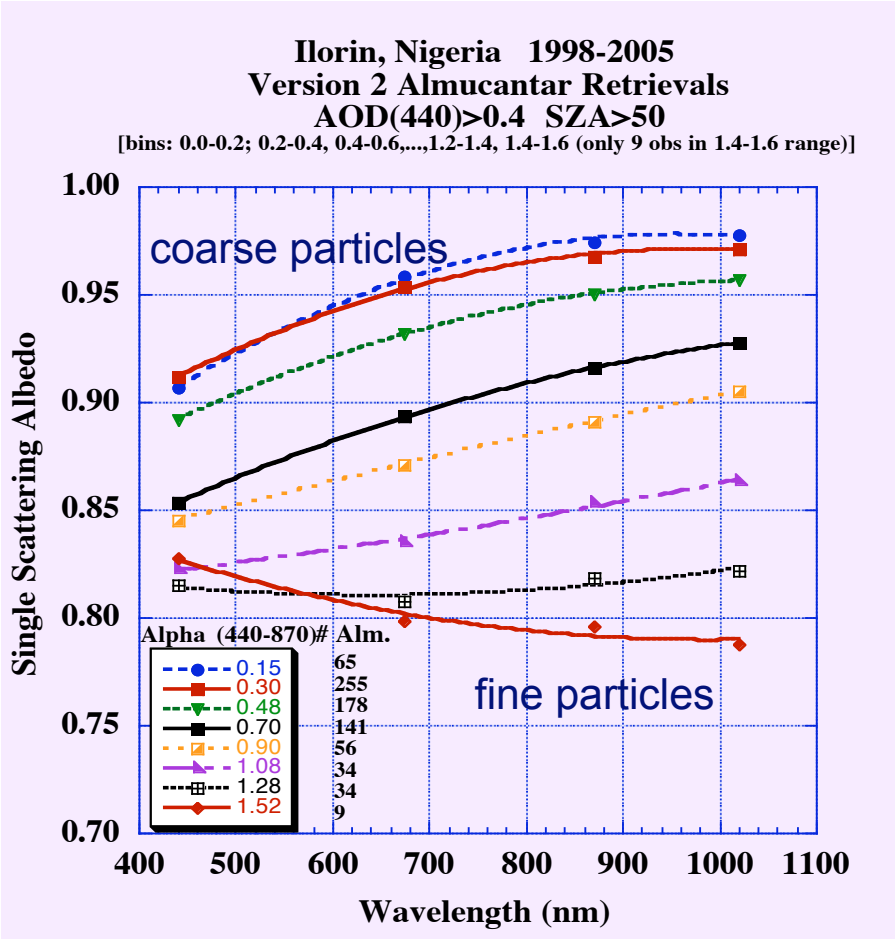
Figure 7. SEM image of dust sample collected on 10 March 2005 at the BoDEx field site. Clearly visible are crushed diatom fragments from the dry paleolake bed.

Photograph of dust aerosol in the dry lake bed

Most particles of sub µm size

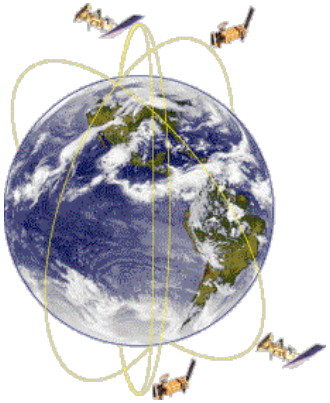
AERONET inversion
Comparison of aerosol from 4 AERONET sites

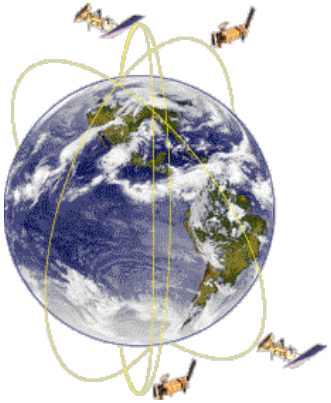




Colors (bins) represent values of Angstrom exponent: The smaller the Angstrom exponent the bigger the particles

3. Satellite sensors for Aerosol retrieval



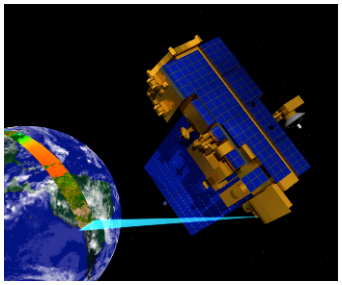


Current Sensors and Satellite Platforms for aerosol retrieval

MODIS	NASA Terra and Aqua satellites
OMI	EOS-AURA (NASA)
TOMS	Nimbus-7 (1979-1993) & Earth Probe (1996-2000)
CALIPSO	CALIPSO (active sensor - Lidar)
AVHRR	NOAA series
GOES	GOES (a geostationary satellite)
POLDER	PARASOL (developed by CNES)
MISR	NASA Terra and Aqua satellites
SeaWiFS	NASA SeaStar
MERIS	ENVISAT
VIIRS	NPOESS (future)
ATSR (or AATSR)	ERS-1, ERS-1 and (ENVISAT)
GOME	ERS-2
SCIAMACHY	ENVISAT

1. MODIS:
Moderate Resolution Imaging Spectro-radiometer; onboard Terra and Aqua satellites

Carries 36 spectral channels: wavelength range: 0.405 μm to 14.25 μm.



Characteristics of MODIS channels used in aerosol retrieval

Band #	Central wavelength (μm)	Resolution (m)	Required SNR
1	0.646	250	128
2	0.855	250	201
3	0.466	500	243
4	0.533	500	228
5	1.243	500	74
6	1.632	500	275
7	2.119	500	110

Note the different resolution

2. TOMS & OMI

TOMS : Total Ozone Mapping Spectrometer (1978 -2000)
OMI: Ozone Monitoring Instrument (launched Jan. 2006 to replace TOMS)

TOMS ◊ Spatial resolution is coarse (100 km average and 50 km at nadir).
OMI ◊

TOMS ◊ Global daily retrievals of Aerosol Index (AI), AOD, and Absorption AOD.
◊ use the UV radiation (330 nm and 360 nm)
◊ UV measurements are less sensitive to the surface and very sensitive to:
1. Aerosol absorption, 2. Altitude of the aerosol plume
◊ turned into the surprise aerosol sensor of the decade.
◊ uses the Aerosol Index defined as

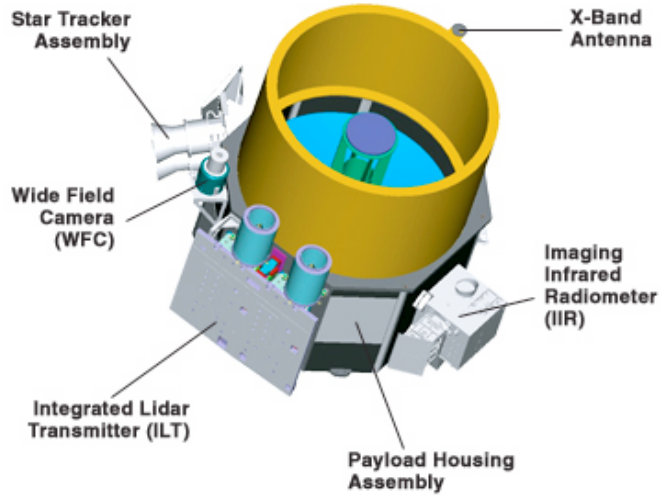
Aerosol Index $$AI = 100 \log_{10}\left[\frac{(I_{330}/I_{360})_{meas.}}{(I_{330}/I_{360})_{calc.}}\right]$$

$I_{meas.}$ ◊ radiance measured by TOMS at a given wavelength,

$I_{calc.}$ ◊ radiance calculated from a Radiative transfer model for a pure Rayleigh atmosphere.

TOMS aerosol index of less than 0.1 indicates a crystal clear sky with maximum visibility, whereas a value of 4 indicates the presence of aerosols so dense you would have difficulty seeing the mid-day sun.

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



◊ Launched 28 Arp 2006

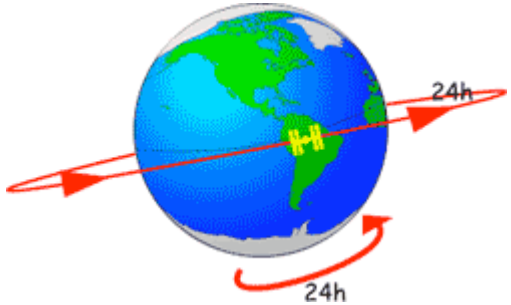
◊ Two-wavelength (532 nm and 1064 nm) polarization sensitive lidar (measures backscatter)

◊ A three-channel IIR: 8.7 mm, 10.5 mm, and 12.0 mm.

◊ Provides high-resolution vertical profiles of aerosols and clouds

◊ Nadir-viewing; non-scanning imager having a 64 km by 64 km swath with a pixel size of 1 km

4. GOES
Geostationary Operational Environmental Satellite



◊ GOES is a series of geostationary satellites since 1981, with new generation since 1994

◊ Primarily a weather satellite. It offers unique opportunity to monitor changes in the earth's surface and subsequent interaction with the atmosphere.

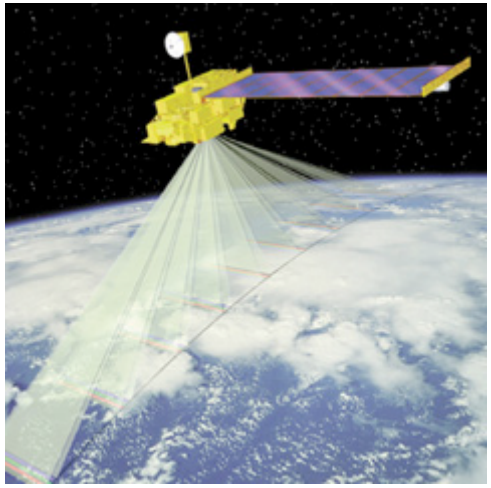
◊ GOES carries visible and IR sensors: 4, μm,11 μm, and 12 μm)

◊ 4 μm and 11 μm bands: used to distinguish smoke/ aerosols associated with biomass burning from clouds

◊ 11 μm and 12 μm bands: used to distinguish haze from low-level moisture.

◊ GOES is interesting because of the temporal dimension:
Aerosol transport associated with biomass burning can be estimated in half-hourly GOES visible and IR images.

5. MISR
Multi-angle Imaging SperctoRadiometer



Nine viewing angles:
-70.5°,
-60.0°,
-45.6°,
-26.1°,
0.0°,
26.1°,
45.6°,
60.0°,
70.5°

◊ Four Spectral bands:
0.45 µm (blue), 0.56 µm (green), 0.67 µm (red) and 0.87 µm (NIR).

◊ Time delay between adjacent camera views is 45-60 seconds, which results in a total delay between the first and last images of about 7 minutes

MISR is interesting because of its multi-angle approach

MISR image at 0 degrees simulates MODIS at Nadir

5. SeaWiFS
Sea-viewing Wild Field of view Sensor

◊ Polar orbiting: 8 channels (6 visible and 2 NIR); 1 km Resolution

◊ Provide the global ocean color and ocean bio-optical property data,

◊ However, SeaWiFS also produces the aerosol optical property data over global ocean: AOD and Ångström exponent) over global ocean

◊ SeaWiFS has generated both global aerosol (over ocean) and ocean color data

7. POLDER on PARASOL platform

French-built small satellite PARASOL (Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar)

◊ POLDER: Polarization and Directionality of the Earth's Reflectances
Imaging radiometer/ polarimeter

◊ Studies the radiative and microphysical properties of clouds and aerosols.

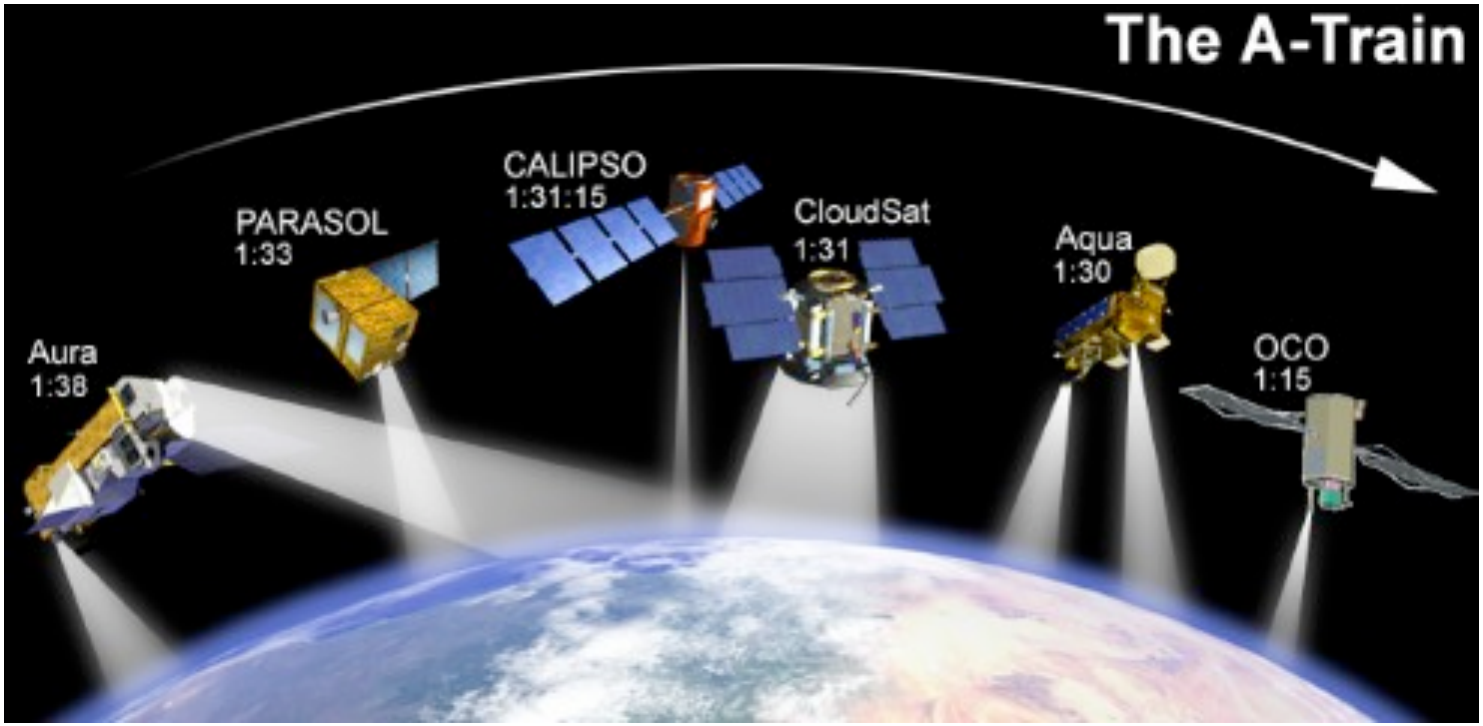
◊ Measures at nine wavelengths:
443, 490, 565, 670, 763, 765, 865, 910 and 1020 nm;
and in different directions and different polarization

◊ Solar radiation becomes polarized when scattered by certain particles such as aerosols, water droplets or ice crystals

◊ POLDER characterize clouds and aerosols more accurately than traditional methods that only rely on their spectral signature.

NASA's A-Train consists of 6 satellites flying in close proximity

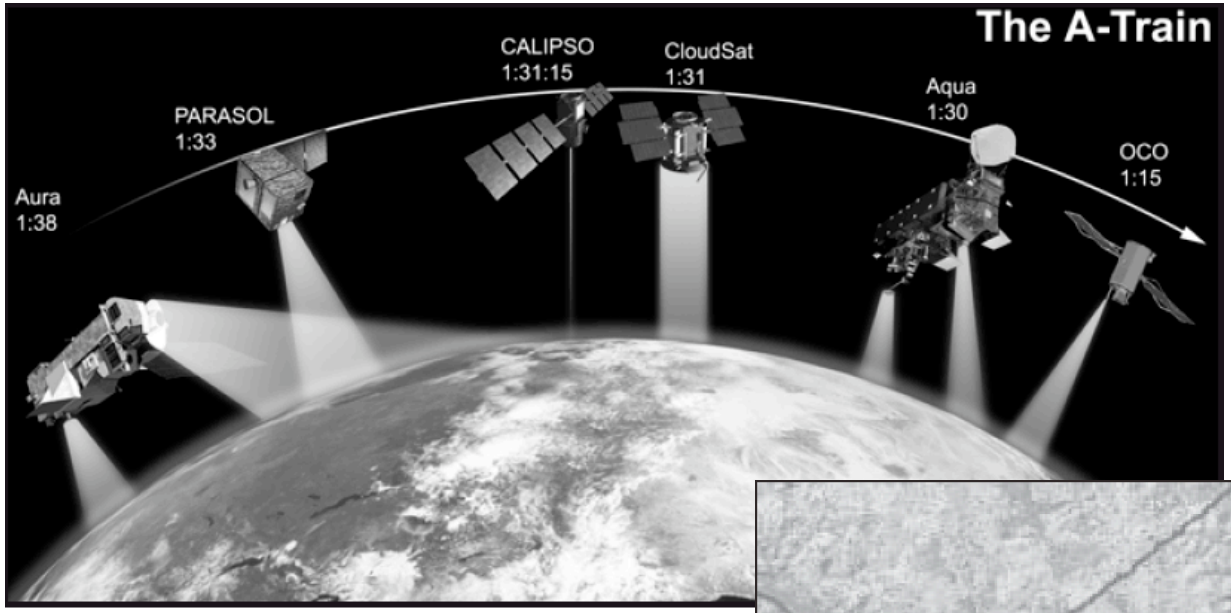
Revolutionary concept: coordinated measurements to obtain comprehensive information about atmospheric components or processes

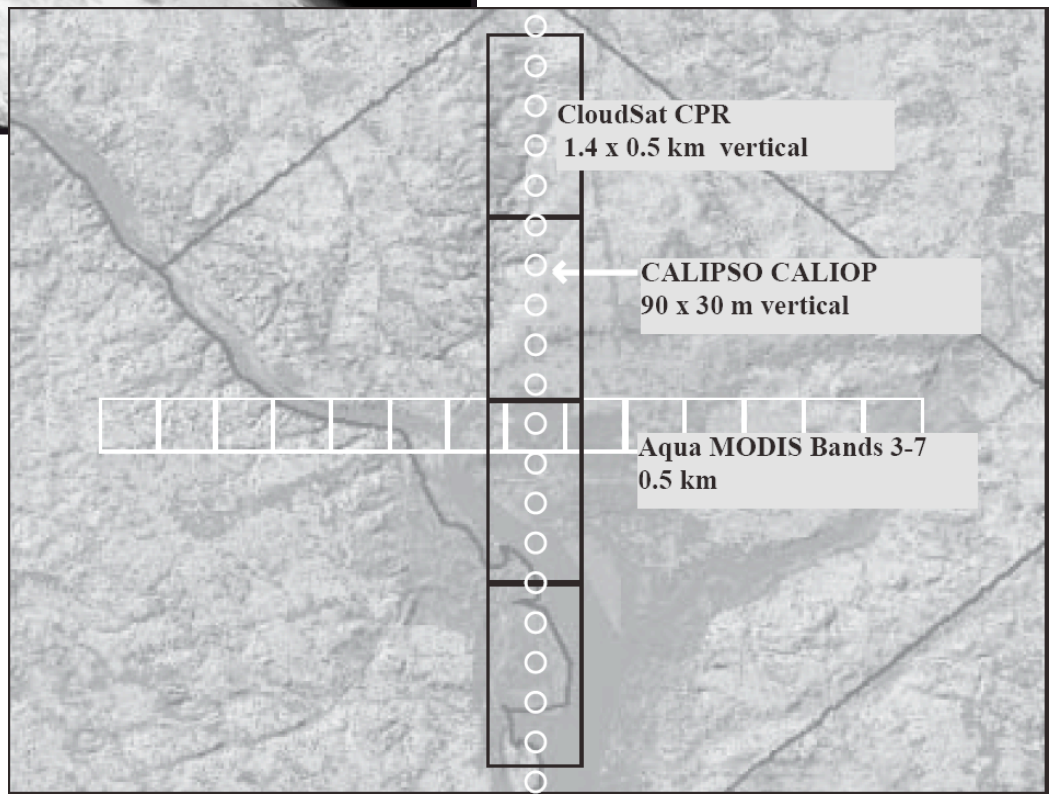


OCO (2008), Aqua (2002), CloudSAT (xxxx), CALIPSO (2006), PARASOL (2004), Aura (2004)

Data can be used together to obtain comprehensive information about atmospheric components or processes.

using the A-Train: a researcher from Dalhousi Univ. developed a method to calculate SSA from MODIS + OMI (cannot be obtained from MODIS alone).

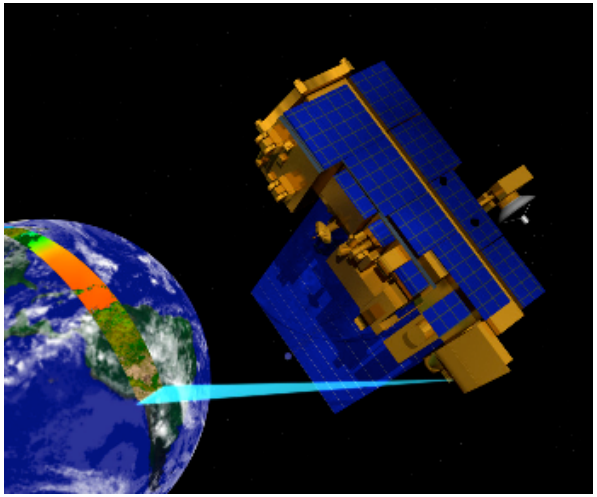




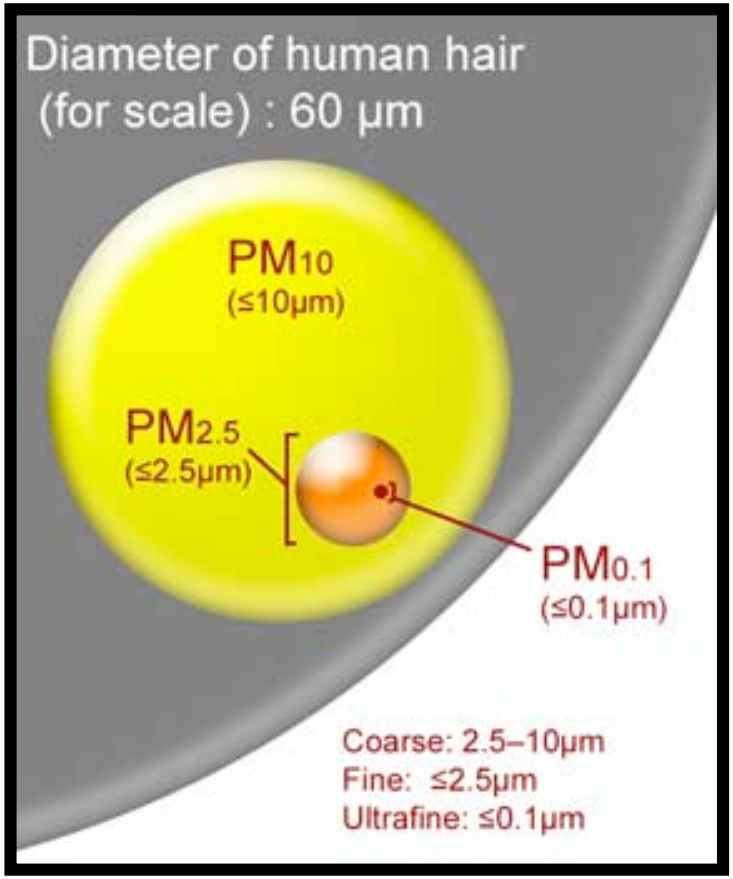
◊ *The precise alignment required to successfully obtain a synergistic measurement: (in this case cloud layering).*

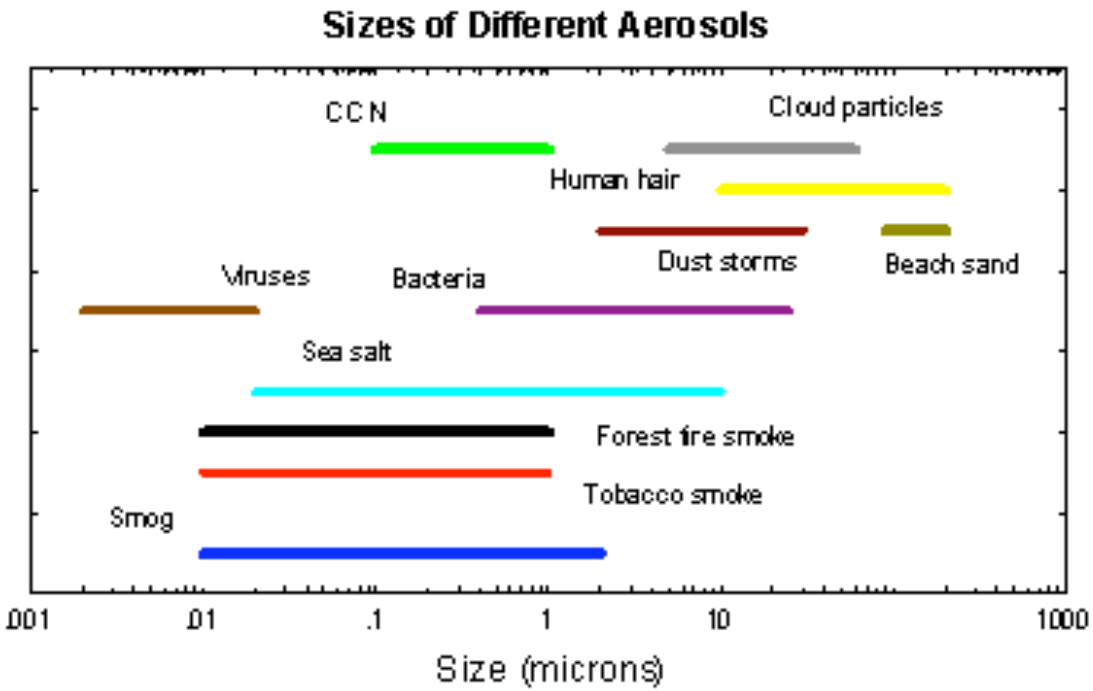
◊ *One of the most engineering challenges with formation flying*

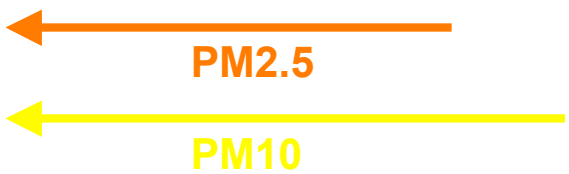
4. Aerosol Retrieval Algorithm from MODIS Satellite Data



Aerosol basics







In remote sensing: Coarse aerosol has a range of mean radius between 0.5 µm and 1.0 µm but also with "tail distribution" up to a few µm.

<u>The main issue in aerosol parameter retrieval from satellite data:</u>

Satellite signal is composed of contributions from:

◊ surface,
◊ atmospheric gases (absorption),
◊ clouds
◊ Aerosol

Aerosol information can be retrieved when the effects of the other three factors are minimum or accounted for.

Favorite conditions for aerosol parameter retrieval from satellite data:

1. Earth surface must be fairly dark,
   i.e. received signal is generated mainly from the atmosphere.

   Over ocean: *remote sensing of aerosol is more accurate and informative*

   Over land: *detection of Dense Dark Vegetation (DDV) using the Atmospherically Resistant Vegetation Index (ARVI) and then the aerosol retrieval over DDV (MERIS approach)*

   Innovative approaches are being examined to determine aerosol over bright surface targets (e.g. snow or desert)

2. No contribution from clouds (cloud contamination kills the aerosol signal)

   ◊ *Aerosol retrieval is available only under cloud-free sky*
   ◊ *This requires a very accurate cloud screening method*
   ◊ *Possible overestimation of AOT due to cloud contamination*

Aerosol retrieval algorithms from different sensors:

Retrievals algorithms are more or less standard in that they depend to varying degrees on weak surface reflectance.

However they differ, depending on the sensor, as follows:

◊ **MODIS** uses of SWIR channels for identifying DDV pixels and estimating their reflectance in the visible,

◊ **MISR** uses large angle measurements which enhance the AOD retrieval,

◊ **OMI** uses UV channels which are less sensitive to surface effects,

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

Main features of MODIS aerosol retrieval:

- One algorithm with two major components: for ocean and for land

- Retrieves the following parameters over oceans and the moist parts of the continents) on a daily basis:
  - ◊ aerosol optical depth
  - ◊ proxies for the size distribution (only over ocean) [$0.55\mu m \leq \lambda \leq 2.13\mu m$]
  - ◊ dust is sensed only over ocean
  - ◊ aerosol mass concentration

- Using a Radiative Transfer Model (RTM), establish a Look-Up Table (LUT) of
  TOA radiation assuming certain surface, atmosphere, and aerosol parameters.

- MODIS-measured spectral reflectance is compared with spectral reflectance from the LUT to find the 'best' (least-squares) fit.

- A few filters are used to qualify the parameter retrieval:
  - ◊ Cloud masking, sediment masking, ocean glint, etc.
  - ◊ Some filters depend on surface or atmospheric parameters derived from MODIS or other sensors or operational products from major centers.

Aerosol retrieval over ocean:

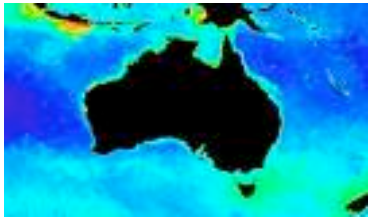
The RTM accounts for the following ocean surface factors:

Specular reflection off the waves (glitter)

Glitter reflectance is several order of magnitude large than aerosol contribution

Should be avoided by retrieving from pixels only within ± 30° solar zenith or azimuth angle.

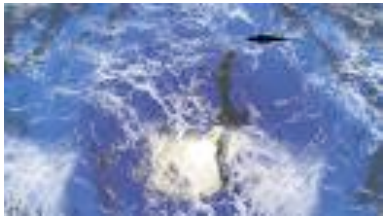
Underwater (sub-surface) reflectance



is determined by marine organisms/ pigment concentrations

Effects:
Pigment ◊ 470 nm wave
Chlorophyll ◊ 659 nm wave
Inorganic particles ◊ 470, 550, 659 nm waves

Surface foam (whitecaps)



Due to breaking waves: Height/wavelength > 0.1

Depends on wind speed

Reflectance from foam is independent of wavelength in the visible and decreases with wavelength in IR range.

In the RTM, foam reflectance is isotropic.

Sun glitter and whitecaps over ocean near Hawaii

The RTM accounts for the Aerosol composition in the atmosphere

Model the aerosol size distribution using a multi-mode log-normal function:

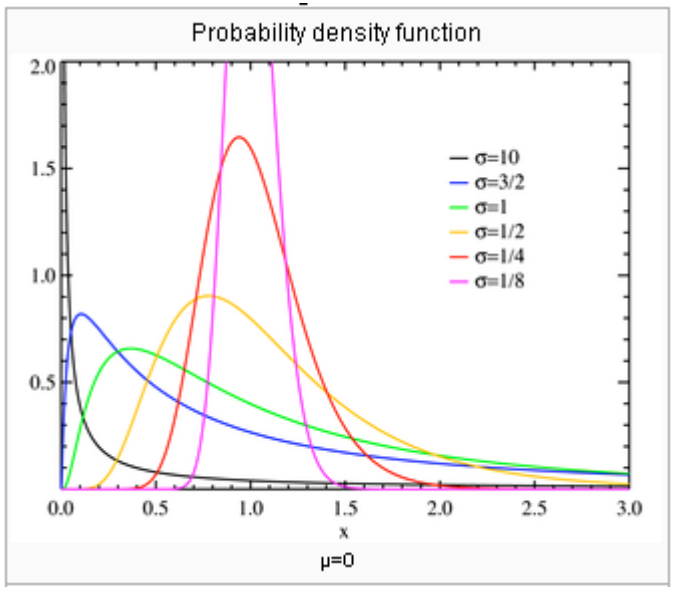
$$n(r) = \frac{dN(r)}{dr} = \frac{N}{(2\pi)^{1/2}\, 2.3\, r\sigma} \exp\left\{ -\frac{(\log r - \log r_m)^2}{2\sigma^2} \right\}$$

N ◊ the number density (cm^{-3}),

r_m ◊ the mean radius (mm)

σ ◊ the standard deviation of log(r),

i.e., $\sigma^2 = \langle(\log r - \log r_m)^2\rangle$.



In the RTM, aerosol is assumed to be composed of two modes: fine and large Therefore a bi-modal log-normal function is used:

$$n(r) = \frac{dN(r)}{dr} = \sum_{j=1}^{2} \frac{dN_j(r)}{dr}$$

Aerosol Model	Median Radius r (μ m)	Standard Deviation s	Refractive Index λ=0.47-0.86 μm
F1	0.07	0.40	1.45-0 .0035i
F2	0.06	0.60	1.45-0 .0035i
F3	0.08	0.60	1.40-0 .0020i
F4	0.10	0.60	1.40-0 .0020i

4 aerosol fine modes:
gas-phase processes & cloud processes

Aerosol Model	Median Radius r (μ m)	Standard Deviation σ	Refractive Index λ=0.47-0.86 μm
C1	0.40	0.60	1.40-0 .0035i
C2	0.60	0.60	1.40-0 .0035i
C3	0.80	0.60	1.45-0 .0035i
C4	0.40	0.60	1.45-0 .0035i
C5	0.50	0.80	1.50-0 .0035i

5 aerosol coarse modes:
maritime particles with dust

Parameters are derived mainly from sun/sky photometers (e.g. AERONET) and from analysis of errors in the products from previous versions of the MODIS algorithm

Tables are established for spectral values of:

◊ Extinction coefficient
◊ Single scattering albedo
◊ Asymmetry parameters

} Parameters used in the model

Spectral Extinction Coefficient for the aerosol modes used in MODIS LookUp Table for the ocean algorithm

λ (μm)/ Mode	0.466	0.533	0.645	0.855	1.24	1.64	2.12
F1	1.43E-10	9.33E-11	6.15E-11	2.66E-11	7.91E-12	4.30E-12	1.48E-12
..							
C1	2.69E-08	2.78E-08	2.84E-08	2.85E-08	2.55E-08	2.12E-08	1.63E-08
..							

◊ **Measured spectral reflectance** is determined from the measured radiance at each wavelength

$$\rho_\lambda^m = L_\lambda \frac{\pi}{F_\lambda \cos(\theta)}$$

L_λ measured spectral radiance

F_λ Solar irradiance at wavelength λ

θ Sun zenith angle

◊ **Calculated spectral reflectance** ρ_λ (in wavelength λ) is obtained from a Radiative Transfer Model (RTM) for each aerosol mode (using its characteristic parameters; and for each one of the following parameters:

The spectral reflectance from the RTM is calculated using the following parameters/ processes

- Surface wind speed = 6.0 m/s.
- Multiple scattering by gas and aerosol
- Reflection of the atmospheric radiation by the sea surface.
- Six values of AOD ($\tau_{0.55}$) for the 0.55 µm wavelength:

0.0 0.2 0.5 1.0 2.0 3.0

pure molecular highly turbid atmosphere

- 9 solar zenith angles
  (6°, 12°, 24°, 36°,48°, 54°, 60°, 66° and 72°),
- 16 satellite view zenith angles
  (0° to 72°, increments of 6°)
- 16 relative sun/satellite azimuth angles
  (0° to 180°, increments of 12°)
- Total of 2304 angular combinations

Obtained from satellite & sun viewing geometry

- For each model and aerosol optical depth at 0.55µm, the associated aerosol optical depths were stored for the other six wavelengths.

The reflectance from each mode is combined using the weighting factor η:

$$\rho_{\lambda}^{LUT}(\tau_{0.55}^{tot}) = \eta\, \rho_{\lambda}^{f}(\tau_{0.55}^{tot}) + (1-\eta)\rho_{\lambda}^{c}(\tau_{0.55}^{tot})$$

Where: $\rho_{\lambda}^{LUT}(\tau_{0.55}^{tot})$

is a weighted average reflectance of an atmosphere with a pure fine mode '*f*' and a pure coarse mode '*c*' both with the same optical thickness $\tau_{0.55}^{tot}$

For each of the twenty combinations (4X5) of one fine mode and one coarse mode, the algorithm finds the pair of $\tau_{0.55}^{tot}$ and η that minimizes the error ε

$$\varepsilon = \sqrt{\frac{\sum_{\lambda=1}^{6} N_{\lambda}\left(\frac{\rho_{\lambda}^{m} - \rho_{\lambda}^{LUT}}{\rho_{\lambda}^{m} - \rho_{\lambda}^{ray} + 0.01}\right)^{2}}{\sum_{\lambda=1}^{6} N_{\lambda}}}$$

where N_{λ} is the sum of good pixels at wavelength λ, ρ_{λ}^{m} is the measured reflectance , ρ_{λ}^{LUT} is calculated from the LUT, and ρ_{λ}^{Ray} is the reflectance contributed by Rayleigh scattering.

Construct a table for the computed reflectance ρ_{λ}^{LUT} using different combinations of aerosol (fine and coarse modes)

20 combinations of fine and coarse aerosol modes

11X11 combinations of weighting factors

model comb.	F1/C1	F1/C2	F1/C3	…	…	F4/C4	F4/C5
$\eta = 0$ (0.0 / 1.0)	$\tau_{0.55} = 0.0$ $\tau_{0.55} = 0.2$ .. $\tau_{0.55} = 3.0$ 6 values of AOD						
$\eta = 0.1$ (0.1 / 0.9)							
…… ……							
$\eta = 1.0$ 1.0 / 0.0							

The algorithm proceeds as follows:

◊ Enter the table with the measured reflectance ρ_λ^m

◊ The "best" solution for each combination (of fine & coarse aerosol modes) is the one with accompanying $\tau_{0.55}$ and η that minimizes the error ε

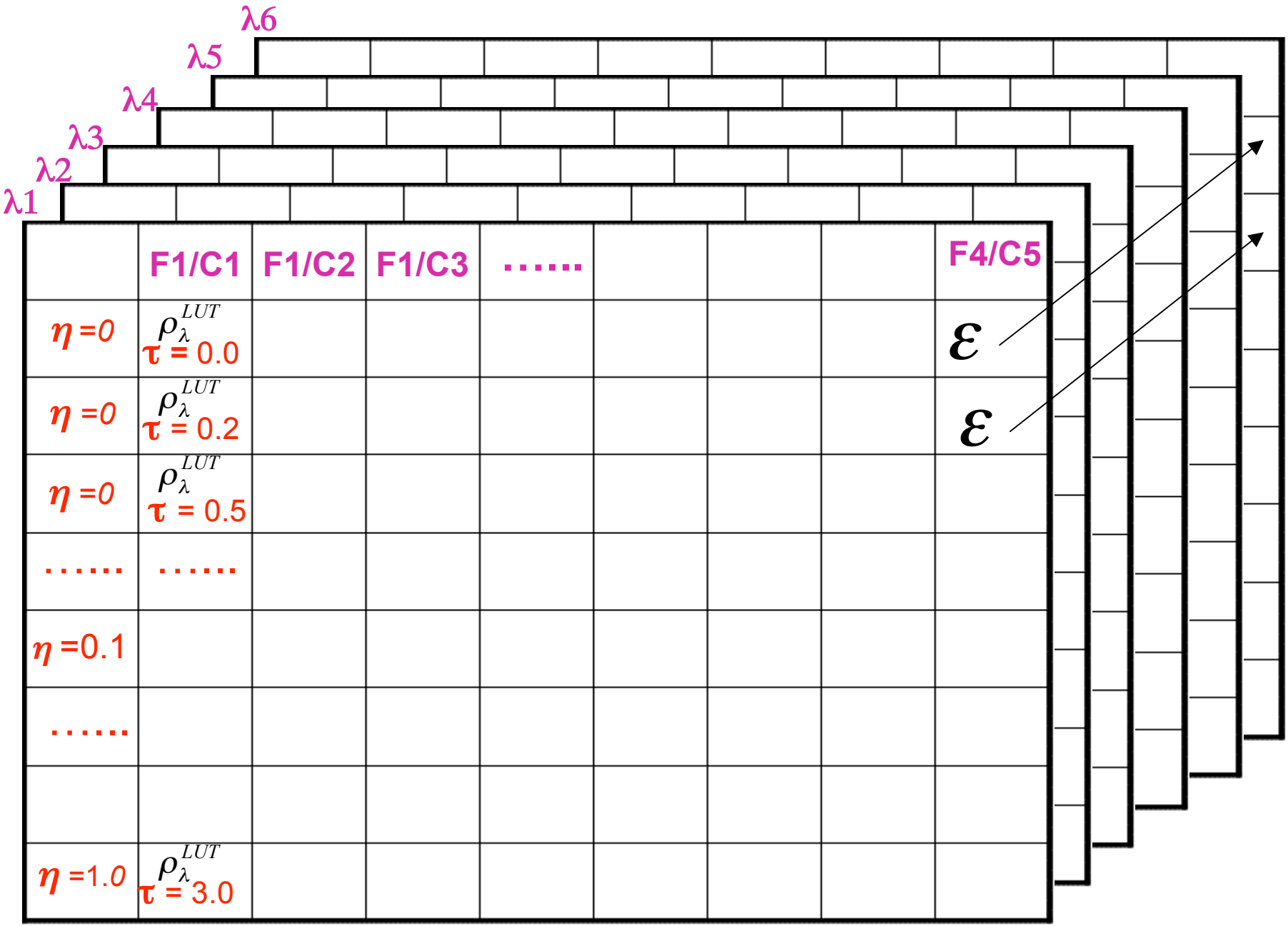
◊ The solution may not be unique

◊ The "average" solution is the average of all solutions with ε<3%, or the average of the 3 best solutions.

◊ Once the solutions are found, then the combination of modes is determined and a variety of parameters can be inferred from the chosen size distribution including:

- spectral optical depth
- effective radius
- spectral flux
- mass concentration

Graphical illustration of minimization of the error between *LUT* and measured reflectance



Pre-processing to aerosol retrieval over ocean

◊ Reflectance from all seven channels are corrected for: water vapor, ozone and carbon dioxide.
for this, the algorithm expects ancillary data from NCEP (National Center for Environmental Prediction) closet analysis (produced every 6 hrs) &
TOVS (before 2005) or the TOAST (after 2005) 1°x1° daily ozone analysis.

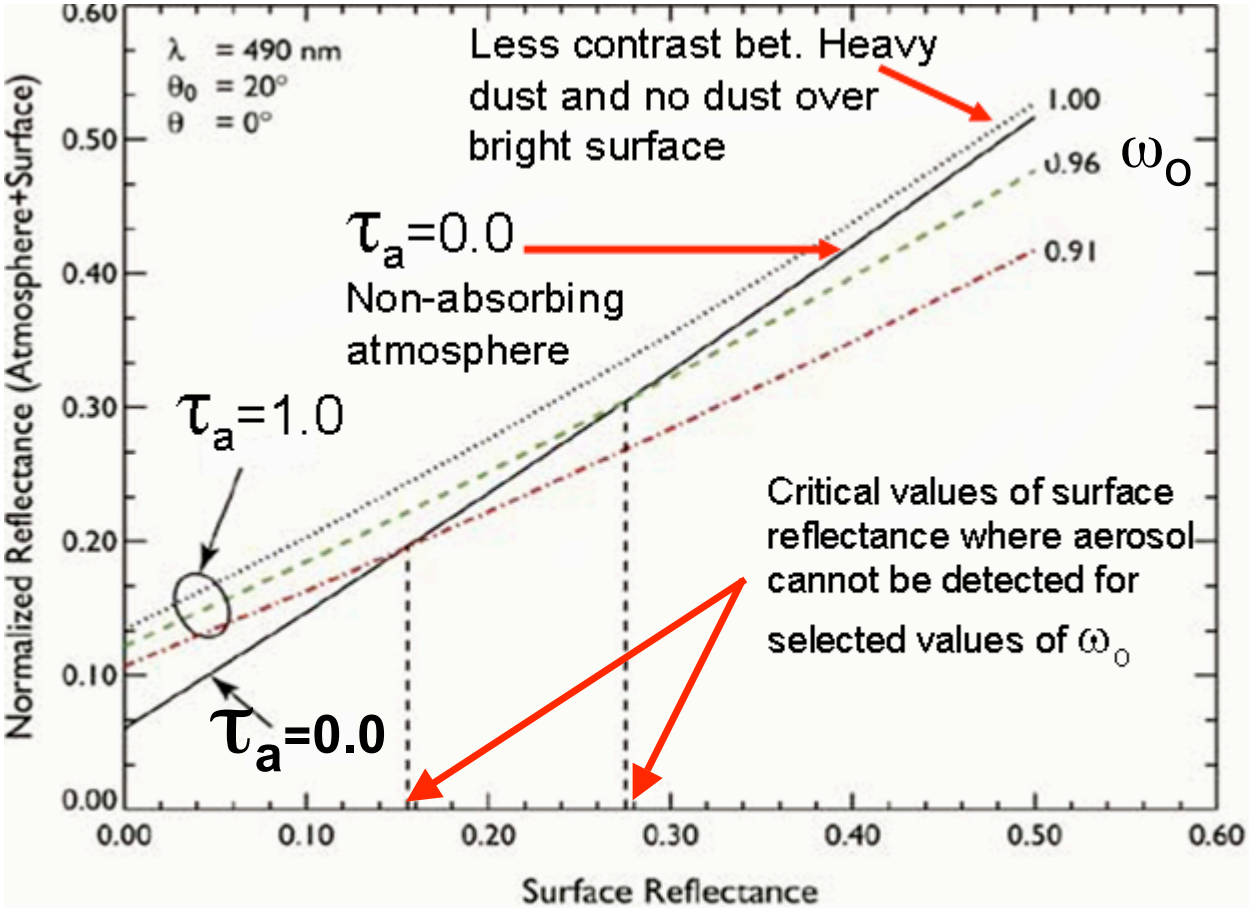
◊ Cloud mask: if $\rho_{0.47} > 0.40$ then cloudy
plus other conditions using $\rho_{1.24}$ and $\rho_{1.38}$,
plus ancillary cloud data from NCEP and Wisconsin.

◊ Glint mask: if $\rho_{0.47} / \rho_{0.66} < 0.95$ then glint dominates (skip calculations)

◊ Sediment mask

◊ Land mask

The challenge of aerosol retrieval over land



Sensitivity of τ_a to SSA for bright surfaces

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) and single-scattering albedo (ω_o).

Source: Aerosol properties over bright-reflecting source regions;
IEEE TGRS, vol 42, No. 3, p.557, 2004

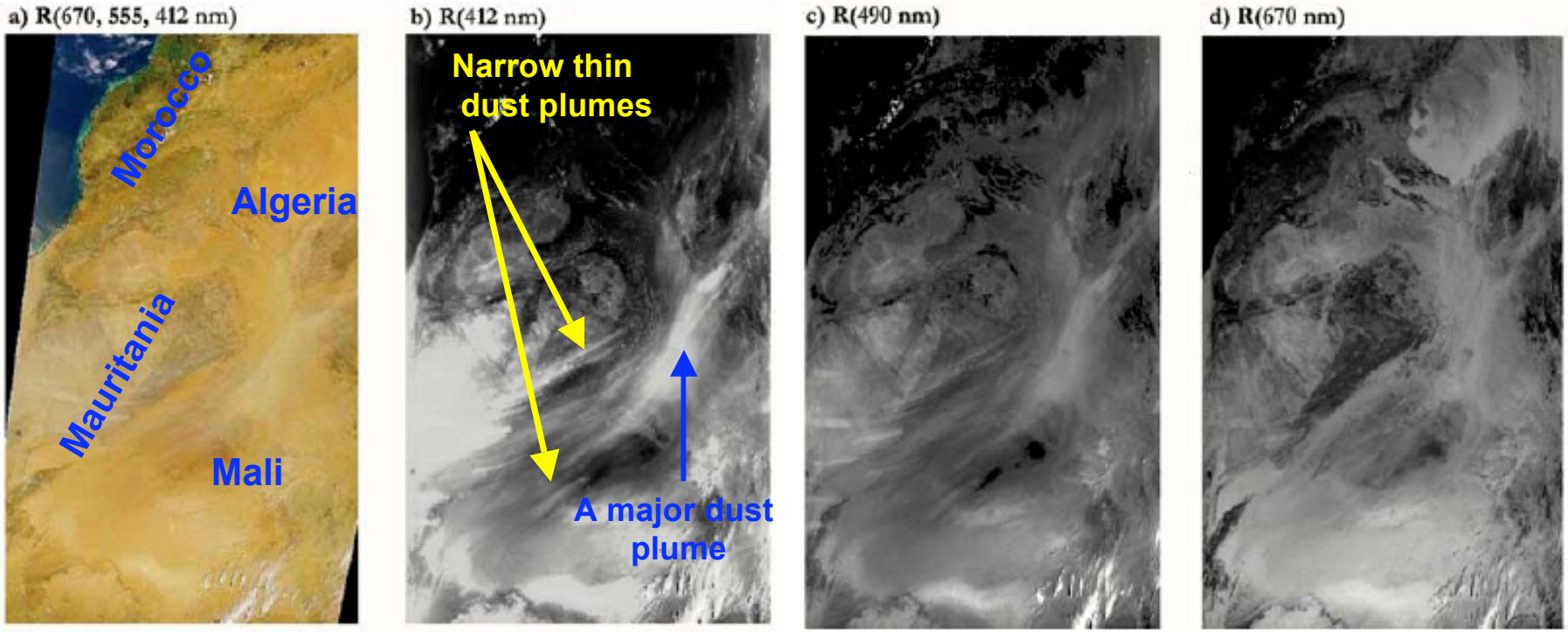
Dust plume may not be seen above bright surface

Reflectance 412, 555, 670 nm

Reflectance 412 nm

Reflectance 490 nm

Reflectance 670 nm



Some of the thin plumes are completely indistinguishable in the 670 nm image.

SeaWiFS images over northeast Africa on February 10, 2001. The dynamical ranges of the grayscale are individually adjusted to optimize the appearance of atmospheric features

Source: Aerosol properties over bright-reflecting source regions;
"Aerosol properties over bright-reflecting soyurce regions; IEEE TGRS, vol 42, No. 3, p.557, 2004

Aerosol retrieval over land:

◊ Retrieval over land is more demanding because the surface reflectance is generally higher, so it provides less sensitivity to changes in aerosols

◊ Reflectance also varies spatially and temporally.

◊ Knowledge of the Bidirectional Reflectance Distribution Function (BRDF), which describes the angular reflectance properties, is required.

◊ Inaccuracies of 0.01 of the surface reflectance can result in AOD variations of 0.1.

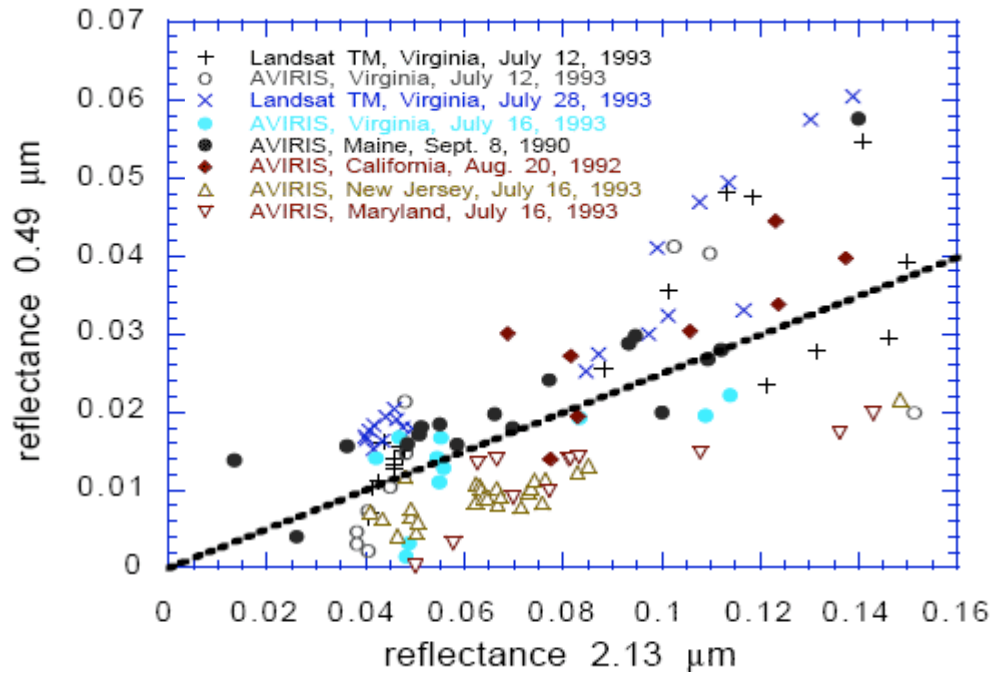
MODIS aerosol retrieval over land: [Dark Target approach]

◊ Same as Ocean module:
i.e. based on look-up table (LUT) approach: radiative transfer calculations are pre-computed for a set of aerosol and surface parameters, then compared with the observed radiation.

◊ But: only over radiometrically dark surface ($\rho_{0.47}$ and $\rho_{0.64}$ are small)

◊ $\rho_{0.47}$ and $\rho_{0.64}$ are correlated to $\rho_{2.12}$

◊ This assumption is valid for most vegetated surfaces but <u>NOT</u> over desert regions



Reflectance at 2.12 µm can be inferred from reflectance at 490 µm

Deep Blue algorithm to retrieve aerosol over bright surface: (arid and semi-arid areas)

◊ Aerosol retrieval at wavelength > 600nm is available only for thick plumes.

◊ Takes advantage of the darker reflectance of “bright surfaces” at blue channels (412 and 490 nm for SeaWiFs; 412 and 470 nm for MODIS).

◊ Global surface reflectance database of 0.1 latitude by 0.1 longitude was constructed over bright surfaces for visible wavelengths using the clearest scene during each season for a given location.

◊ The AOD and aerosol type are then determined simultaneously in the algorithm using lookup tables to match satellite observations.

Basis of "Deep blue" algorithm; dust targets are effectively fairly "dark" in the blue band

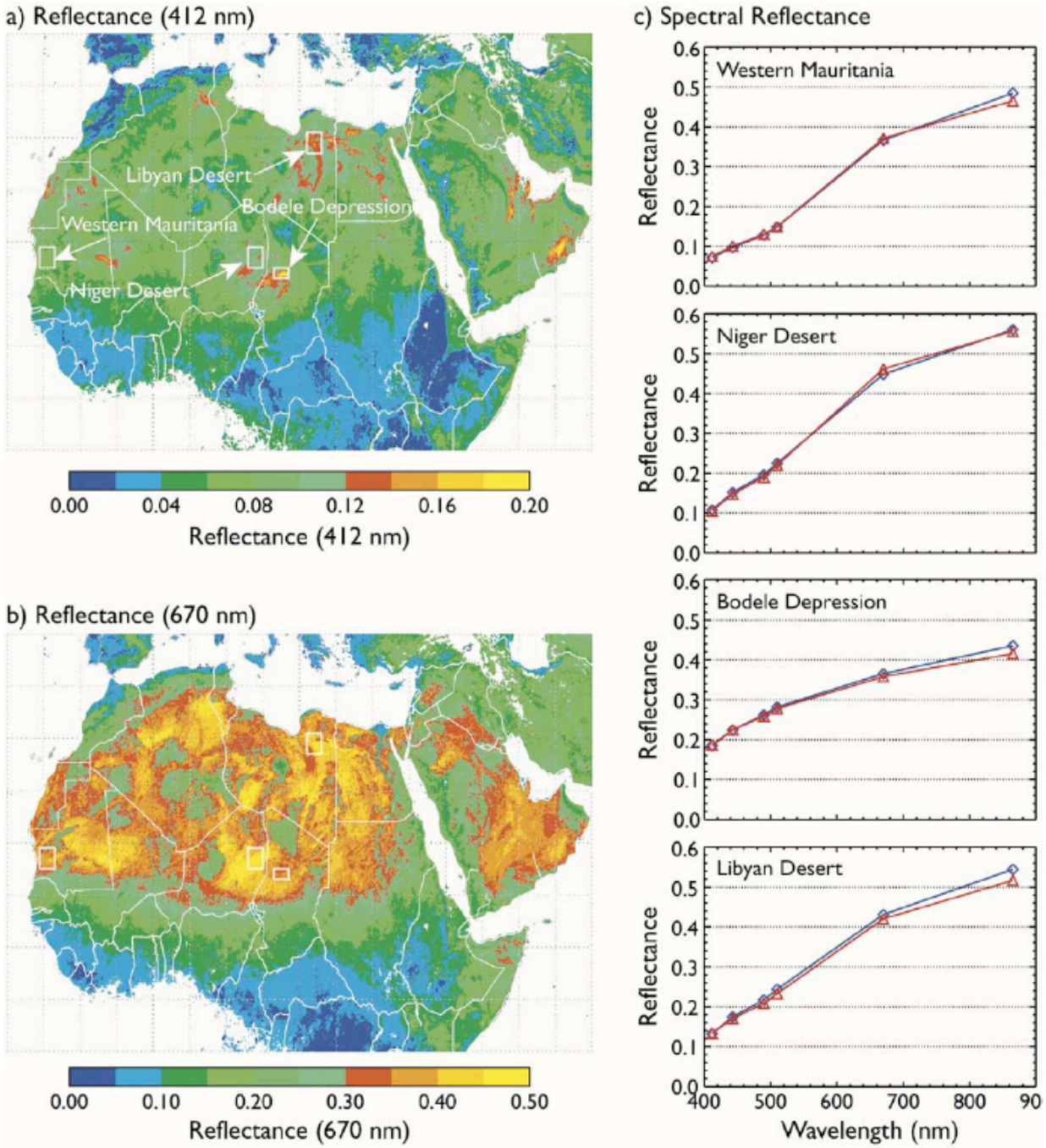
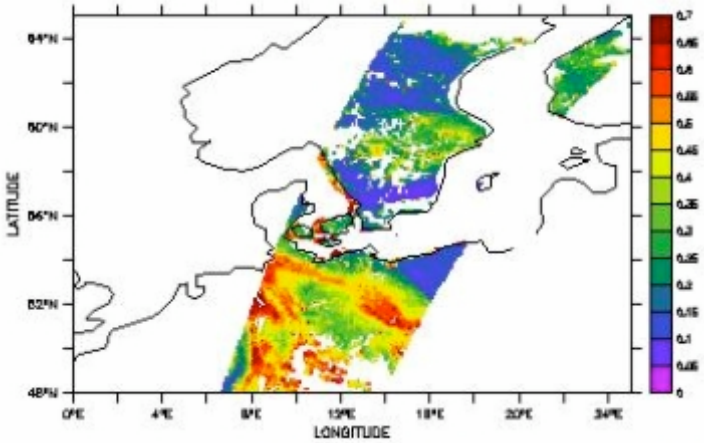
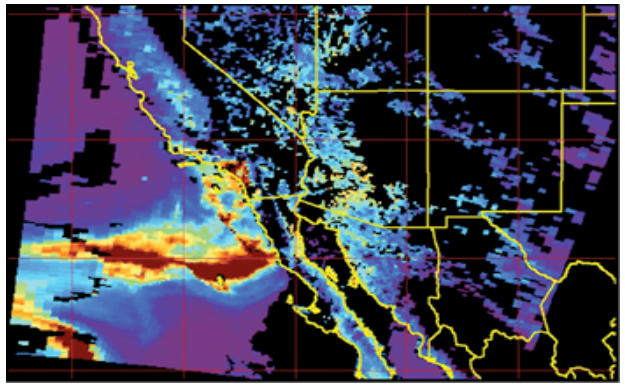


Figure caption and source citation; see "Notes Page" associated with this slide

5. Results of Aerosol Parameter Retrieval from Satellite Data





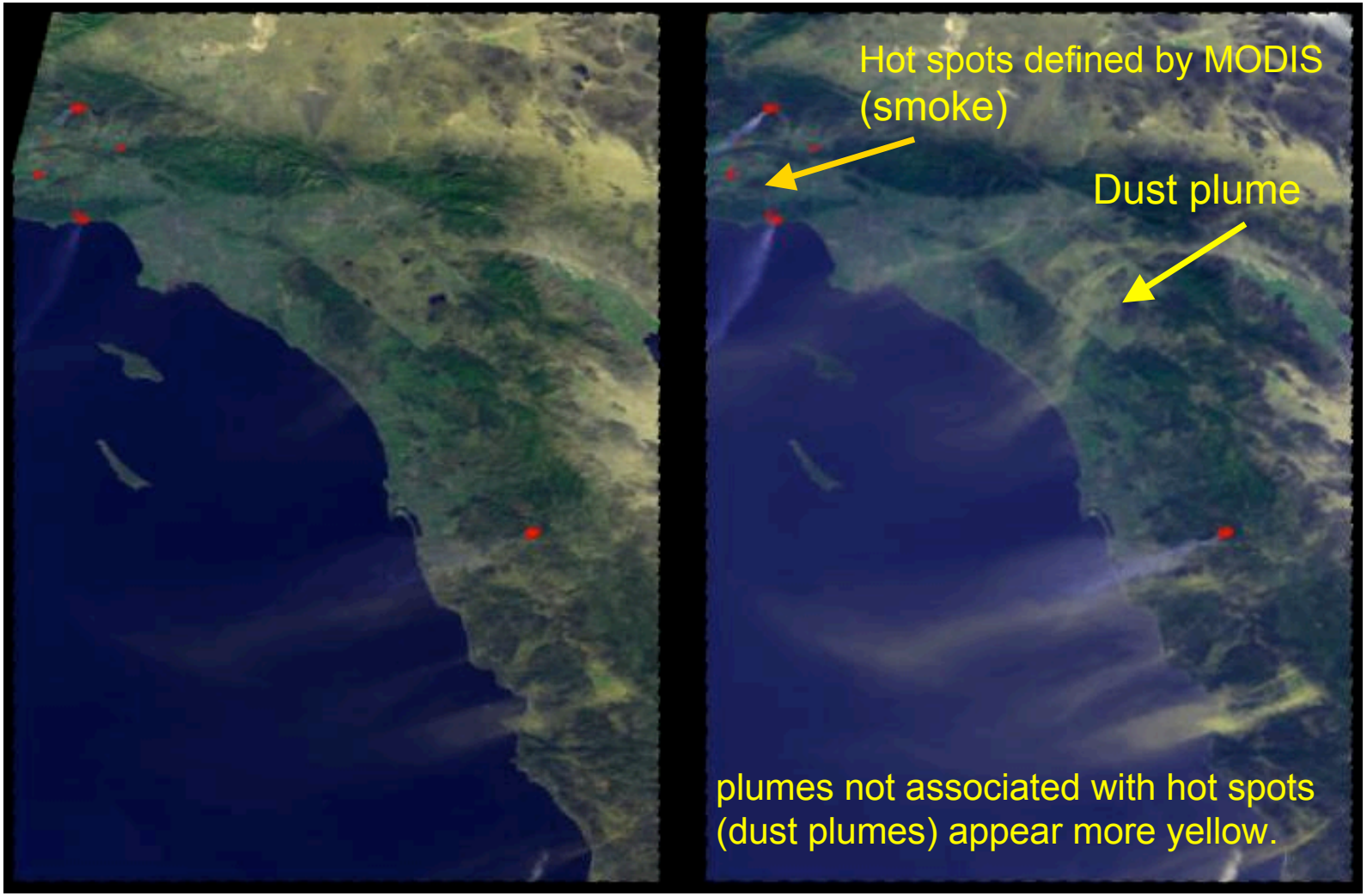
True-color MODIS image for visual analysis
California fires & dust, October, 2003

True-color image of the wildfires in southern California (summer of 2003) taken by MODIS. Shows the smoke plumes of ten raging fires, and the direction of the transport of pollutants.

Advantage of MISR multi-views
(California fires & dust, October, 2007)

Nadir view

60° view (forward looking)



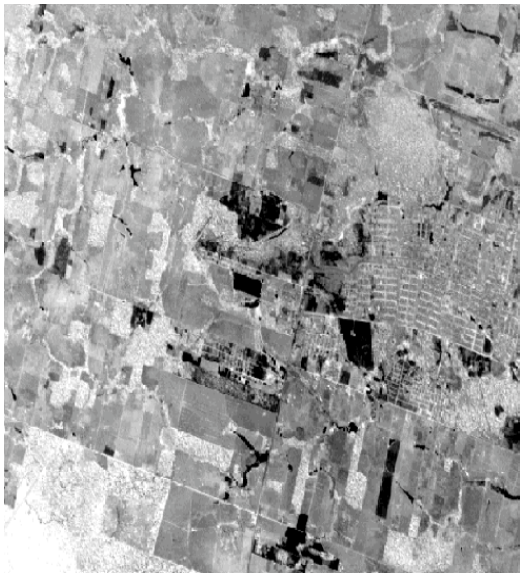
increased look angle has greater backscattering due to aerosols

λ = 0.47µm

λ = 0.66µm

Reflectance at the TOA for high optical thickness of Biomass Burning Aerosols (small aerosol particles)

λ = 0.86µm



λ = 2.3 µm

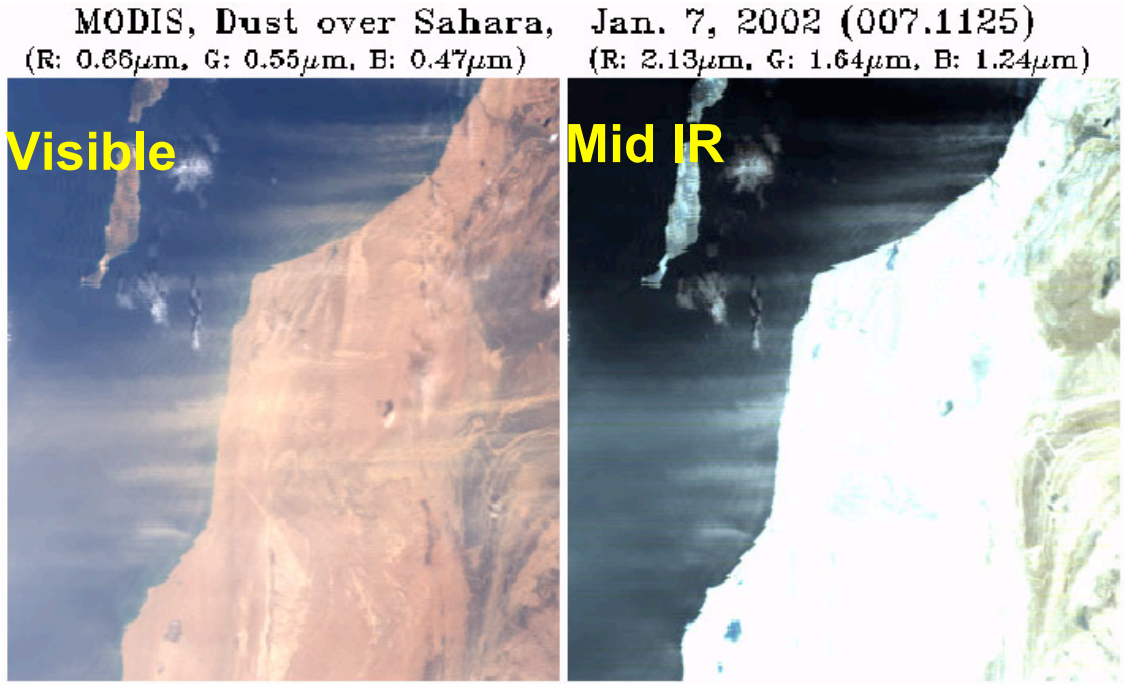
AOD is near-zero at high wavelength: (λ =2.3 µm)

Source: http://lba.cptec.inpe.br/Presentations/Manaus2002/JoseVanderleiMartins-Aerosols-Climate-Interactions.pdf

How can MODIS wide spectral range be used to distinguish between fine and coarse aerosol?

Coarse mode particles (dust):

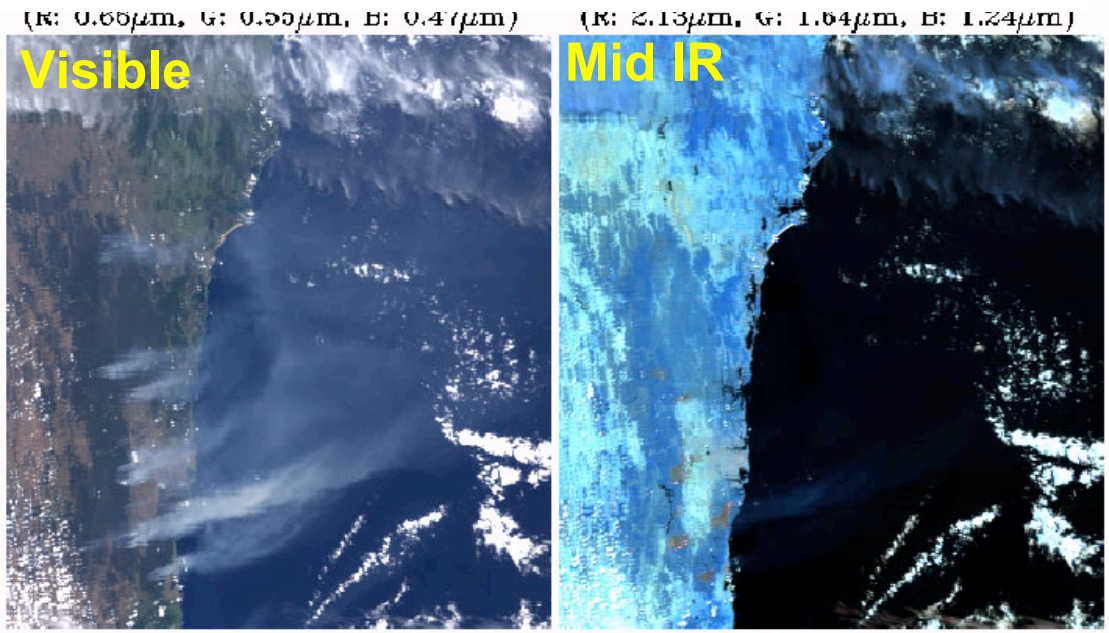
τ remains constant with wavelength



Fire in Australia, Dec 2001

Fine mode particles (smoke):

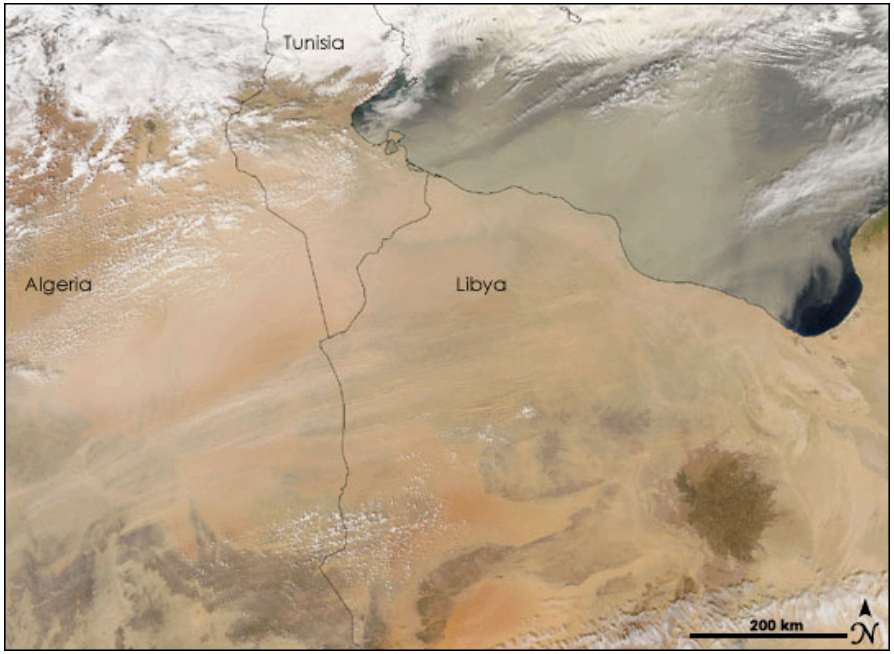
τ decrease rapidly with wavelength



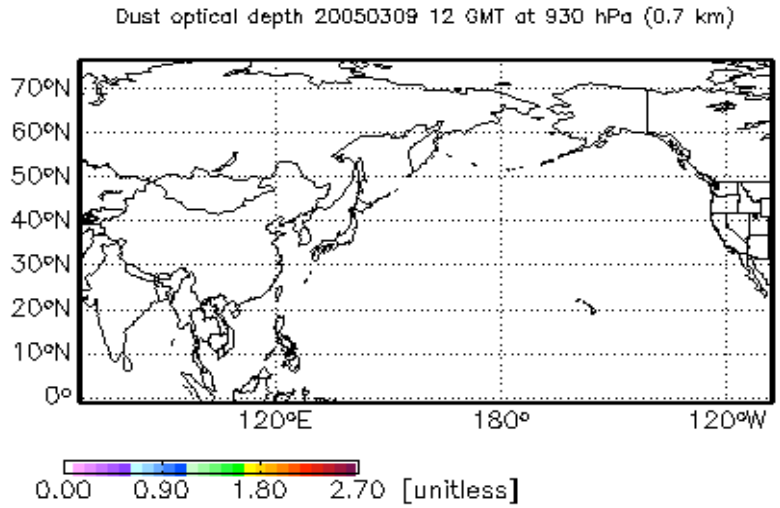
if we see strong aerosol backscatter in the SWIR then it must be dust.

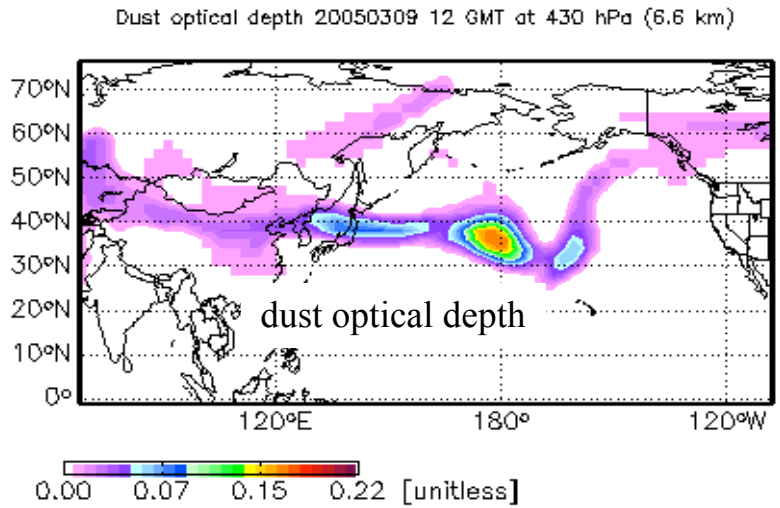
Source; Kaufman et al., Nature 2002

Algerian dust in Vancouver



MODIS (Terra), Mar. 1, 2005



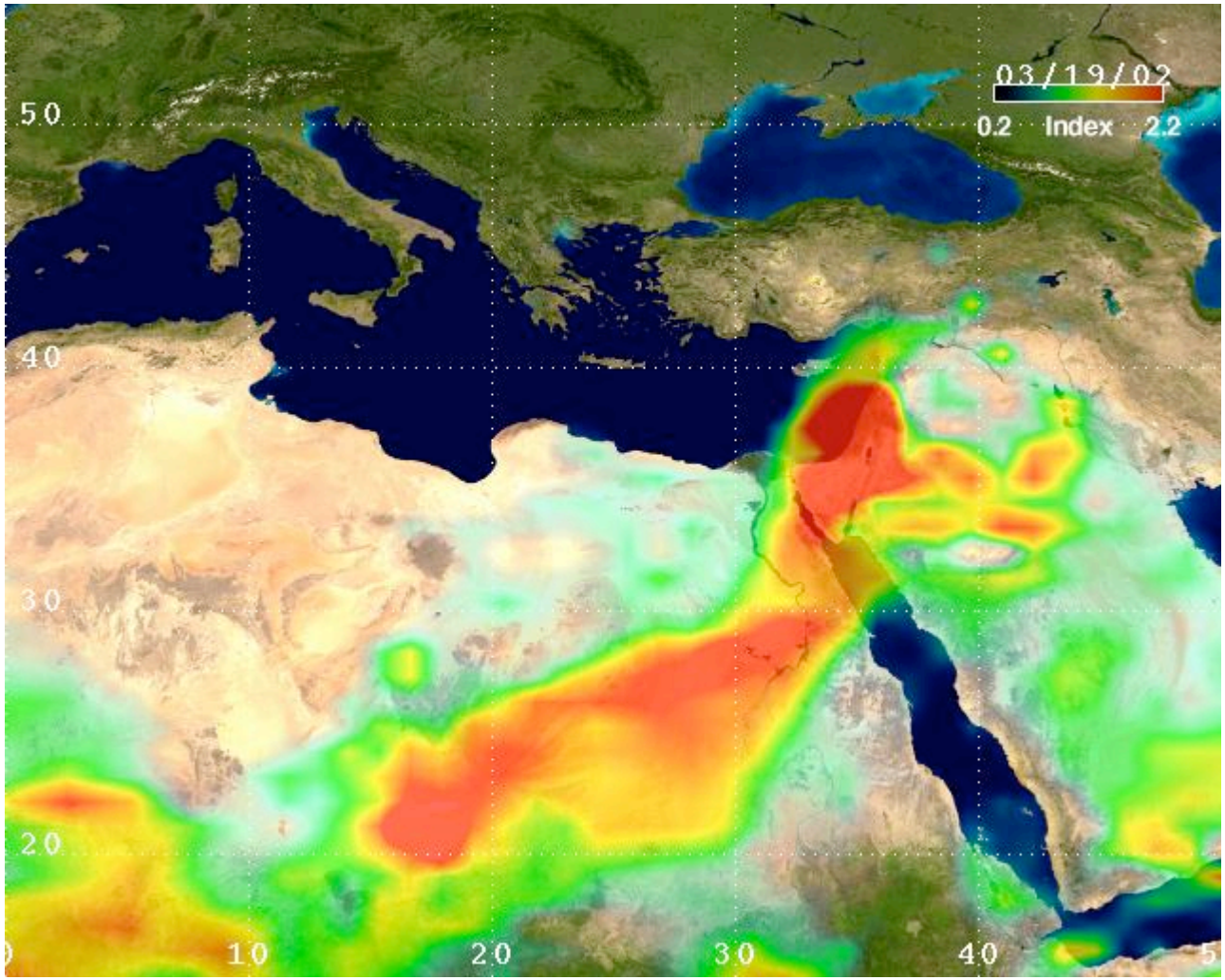


GEOS-CHEM, Mar. 9, 2005

Source: McKendry, I., K. Strawbridge, N. T. O'Neill, A.-M. MacDonald, P. Liu, R. Leaitch, L. Jaegle, D. Farlie, D. Westphal, Trans-Pacific transport of Saharan dust to western North America: A case study, submitted to JGR, Jan., 2006

A composite image from two data sources:

1. The true-color image was made using MODIS data.
2. A false-color representation from the TOMS measurements of aerosol index



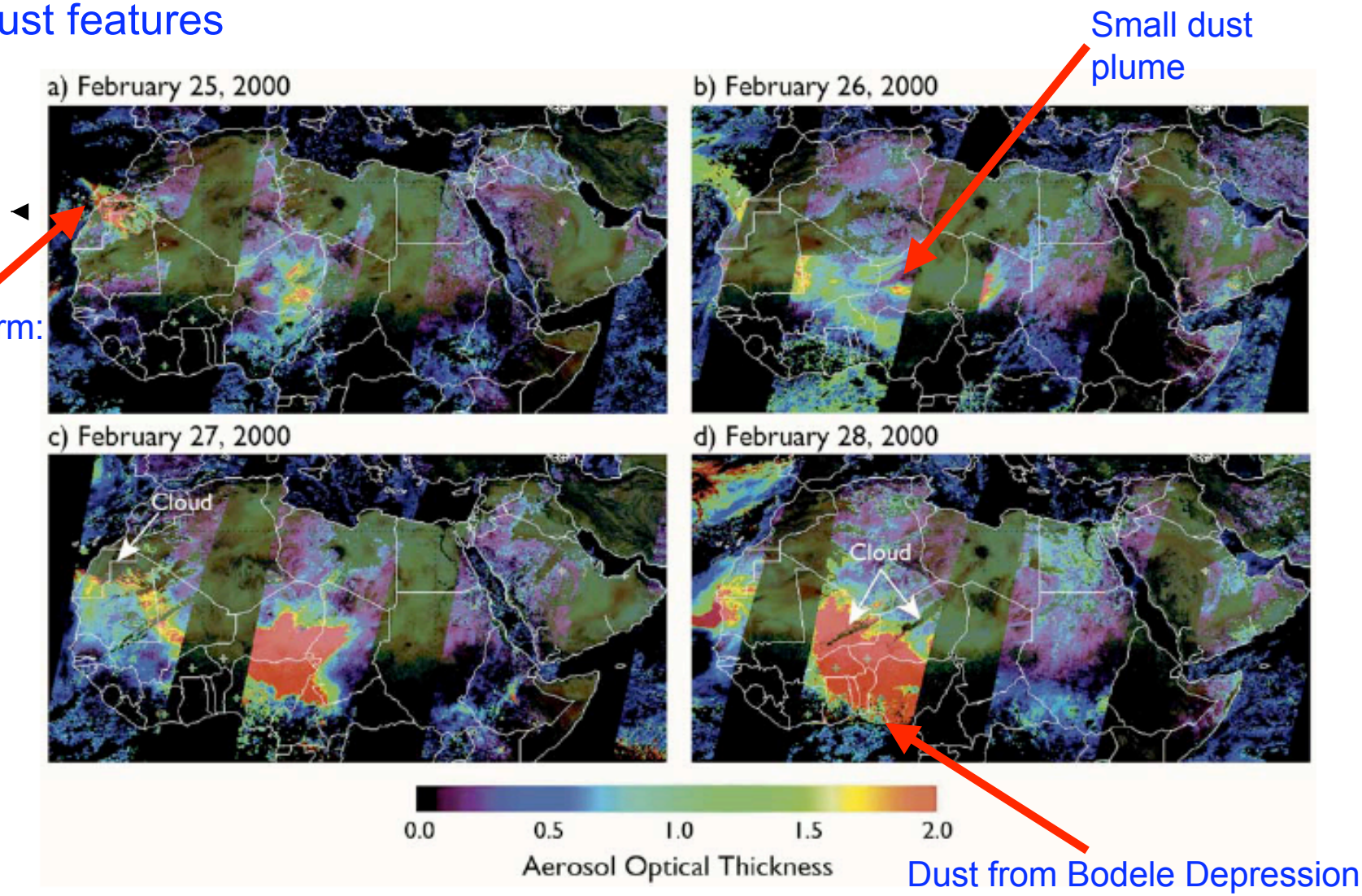
Dust Cloud

A large cloud of dust blowing from northeastern Africa across Egypt, the Sinai Peninsula, over Israel and into the Middle East region on March 19, 2002.

Shows the reason for using DB because the blue wavelength (similar to UV) is insensitive to surface. AOD is much thicker in the blue and UV

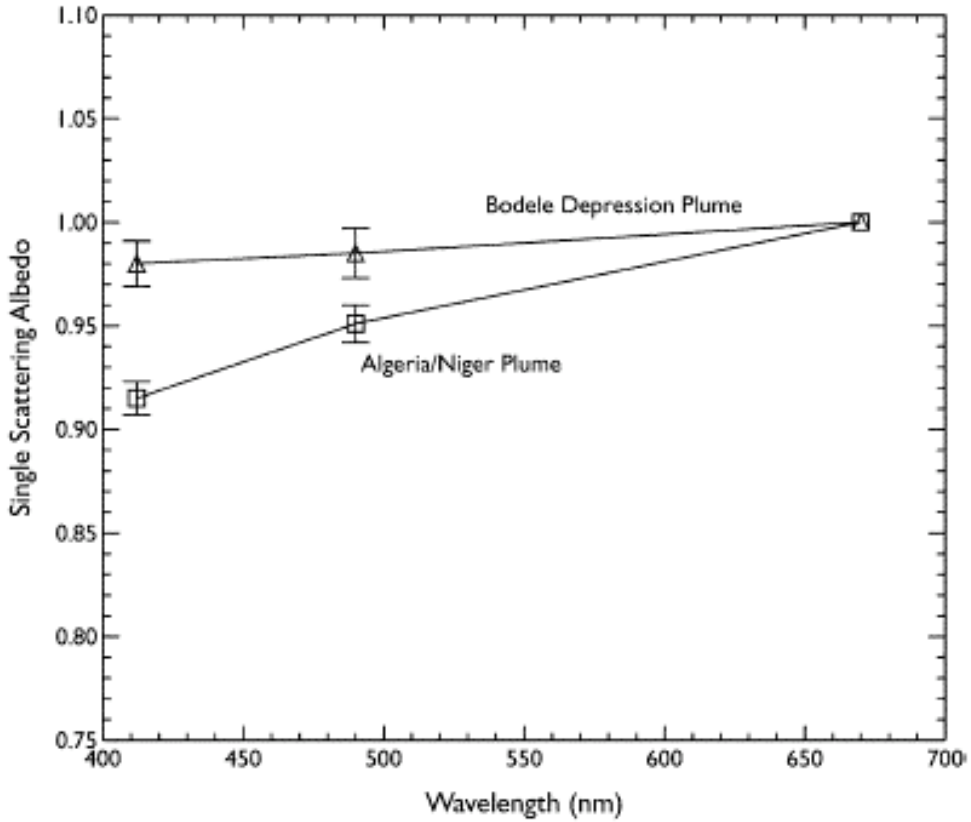
Red areas correspond to high aerosol index values: correspond to the most dense portions of the dust cloud.

Deep blue result from SeaWiFS imagery: 3 main dust features



Source: Aerosol properties over bright-reflecting source regions; IEEE TGRS, vol 42, No. 3, p.557, 2004

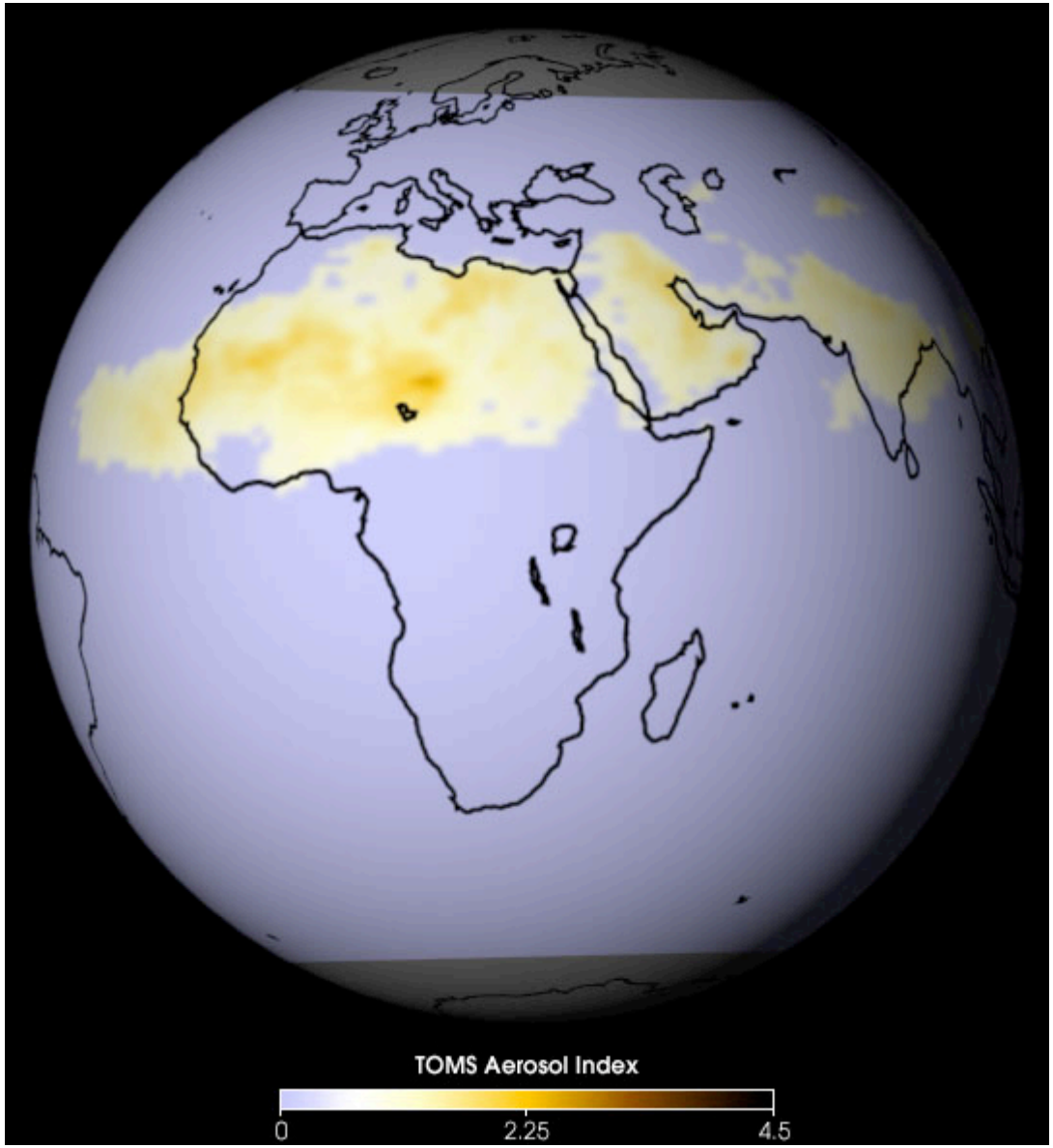
Dust Plumes from from Bodele depression absorb less solar radiation than those from other sources. This information help reduce the uncertainty in the determination of radiative forcing



SSA at 412 and 490 nm retrieved from the Deep Blue algorithm over the region about 100 km downwind of the Bodele depression on February 2, 2000, and downwind of the Algeria/Niger source on February 26,2000. The vertical bars represent the standard deviation of the retrieved values within the selected box.

Source: Aerosol properties over bright-reflecting source regions; IEEE TGRS, vol 42, No. 3, p.557, 2004

Global Aerosol Concentration (Aerosol Index) from TOMS (at UV)



light blue pixels:
little or no aerosol.

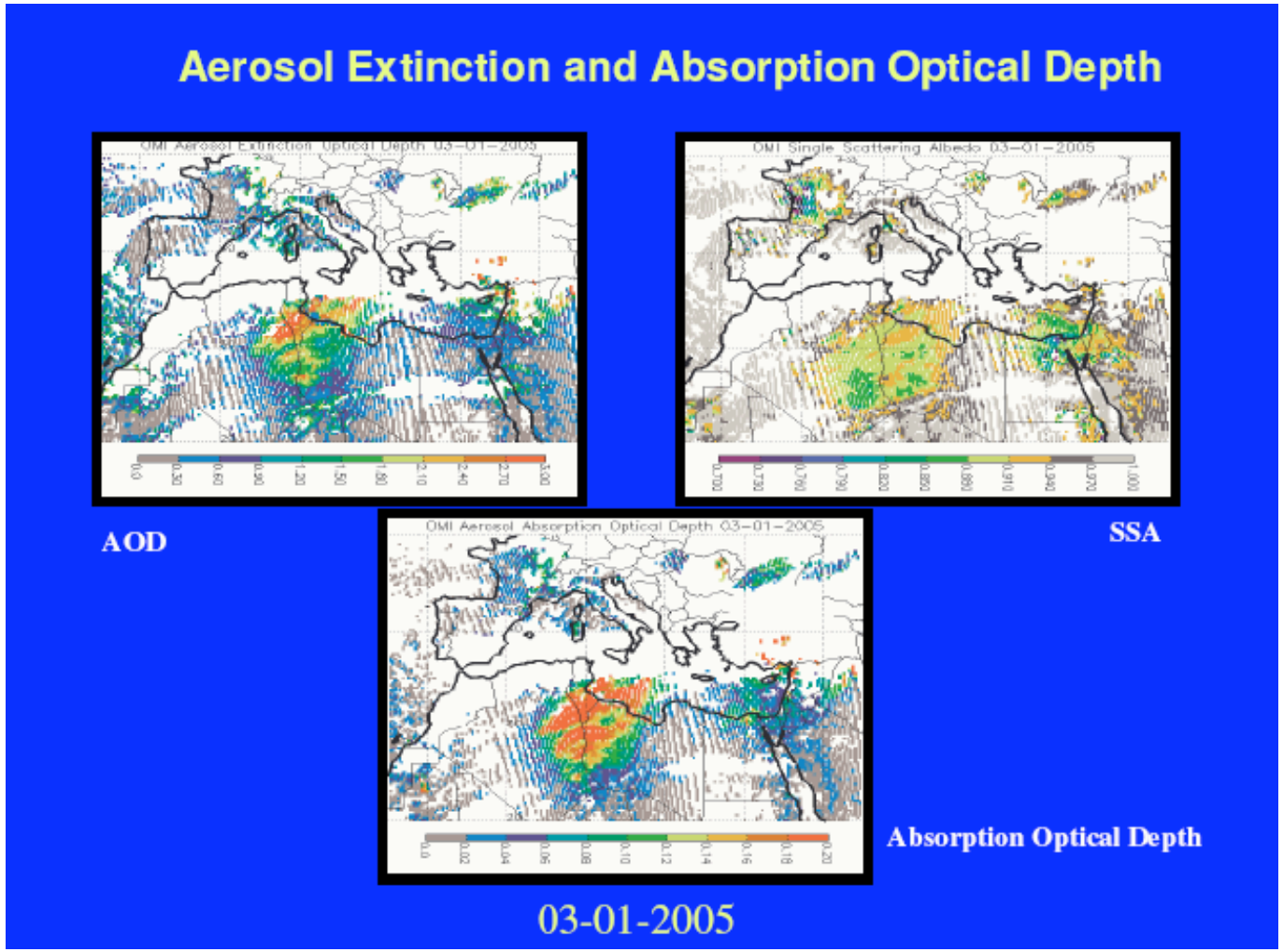
Yellow pixels:
lower aerosol concentration

Brown pixels:
higher aerosol concentration
(mid-day sun difficult to see)

Date: April of 2000

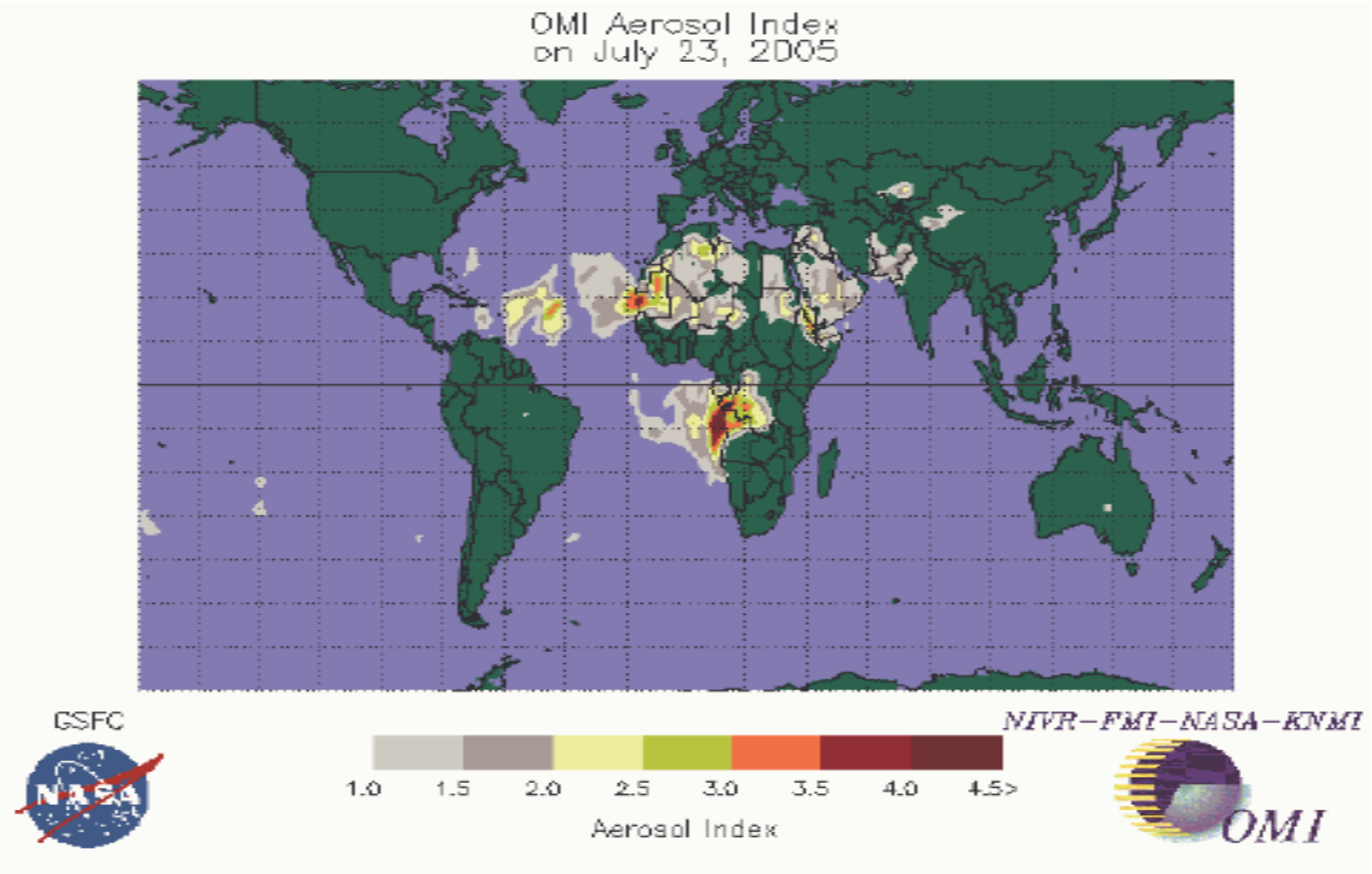
Dust blowing from the Sahara Desert into the Atlantic Ocean, more dust from the Rub' al Khali and Nafud deserts of the Arabian Peninsula, and what may be smoke over northern India.

OMI Aerosol Products: Extinction, Single Scattering and Absorption Optical depth



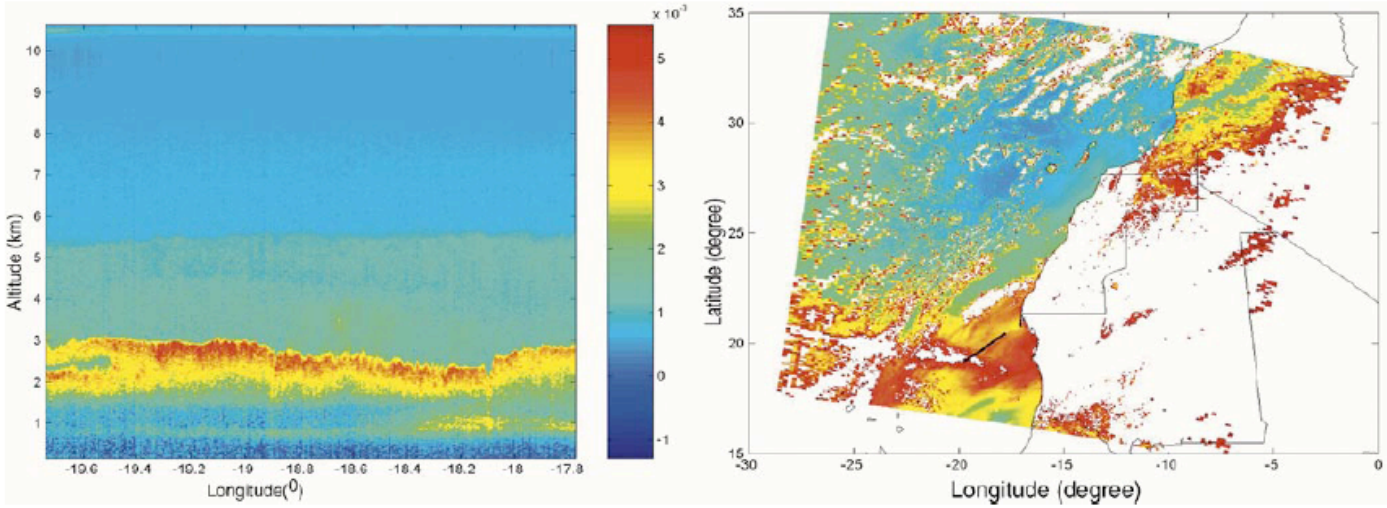
Source: OMI Aerosol Preliminary Validation Evaluation: AURA Validation Workshop Sept.05 Greenbelt, Maryland

Global Aerosols Index from OMI (at UV)



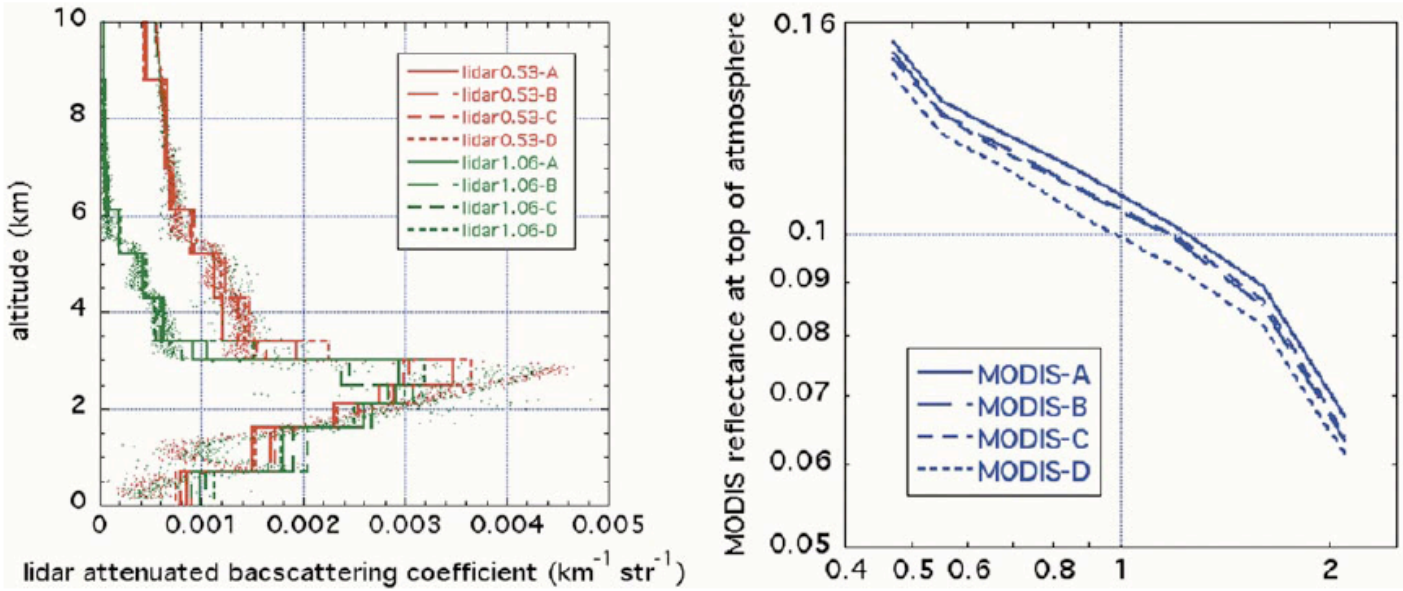
Source: OMI Aerosol Preliminary Validation Evaluation: AURA Validation Workshop Sept.05 Greenbelt, Maryland

CALIPSO/ MODIS inversion to achieve vertical profiles with size-related information



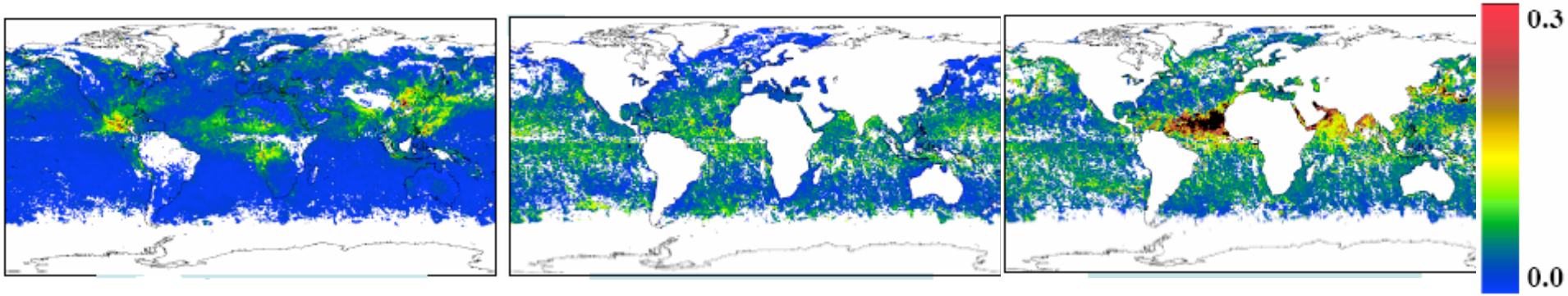
(a) (b)

Fig. 3. (a) Lidar returns at 0.53 μm as a function of height (kilometers) and longitude (°), showing the presence of dust at 2–3-km altitude. The lidar flew at 10.5-km altitude. (b) The MODIS image of the derived aerosol optical thickness is shown. Red colors correspond to high aerosol concentration and blue colors to low. The lidar path is shown in the MODIS image by black line.



(a) (b)

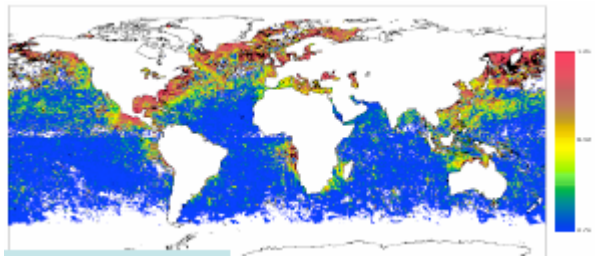
PARASOL - nominal output products (polarization & multi-angle)



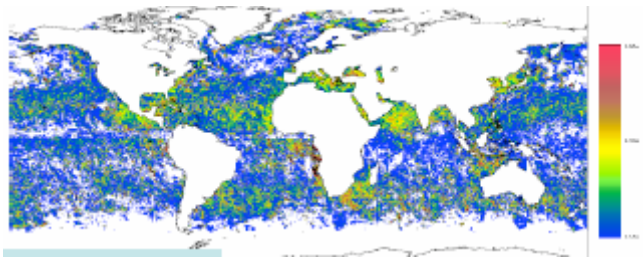
fine mode optical depth

coarse mode optical depth for spherical particles

optical depth for non-spherical particles

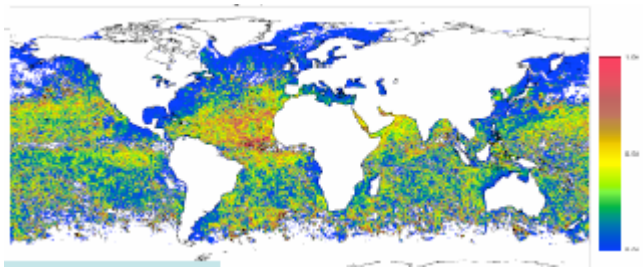


reff=0.07

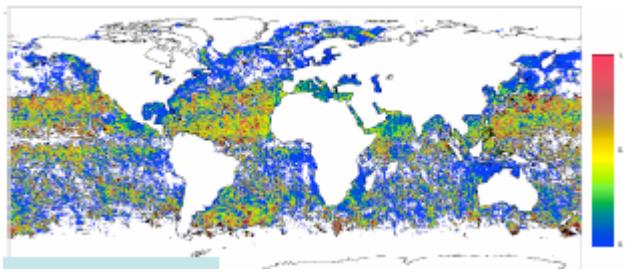


reff=0.13

reff is the effective radius of the fine mode PSD



reff=0.17

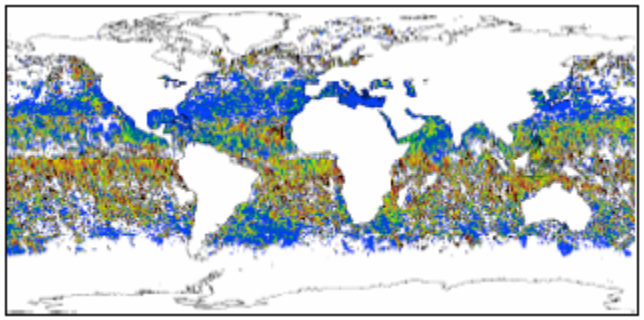


reff=0.22

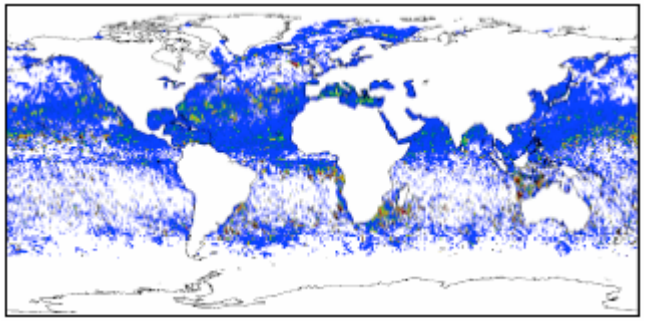
NIVEAU 3
05.2005

index of refraction of the coarse mode (real part).

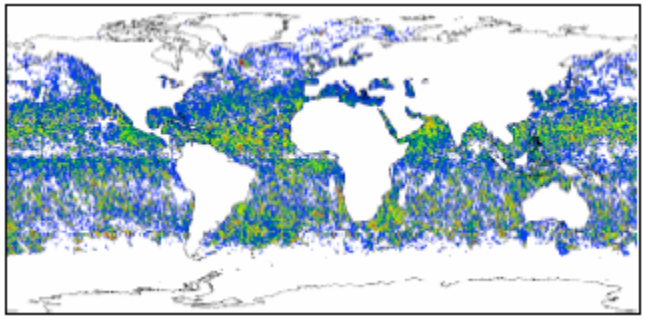
index of refraction of the fine mode (again, the real part)



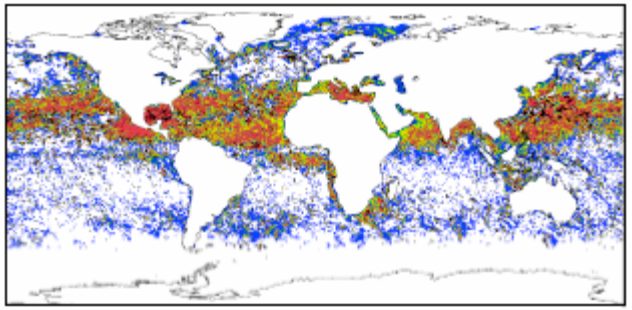
m=1.33



m=1.35



m=1.35



m=1.45

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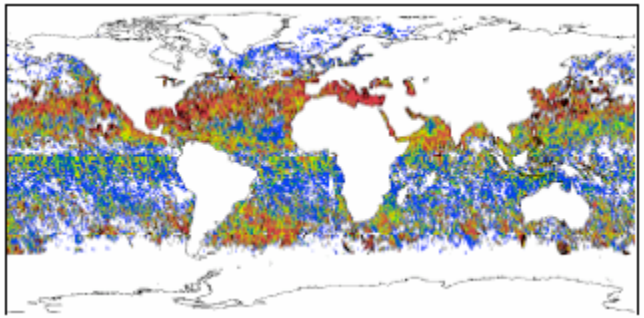
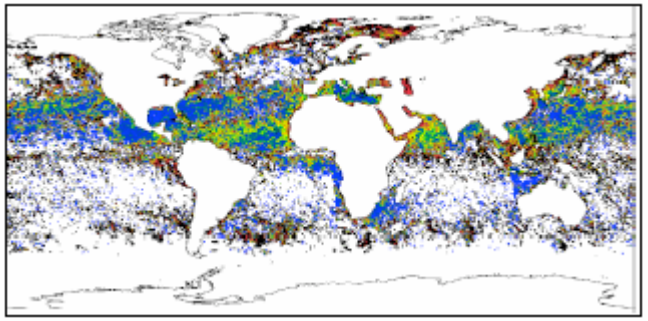
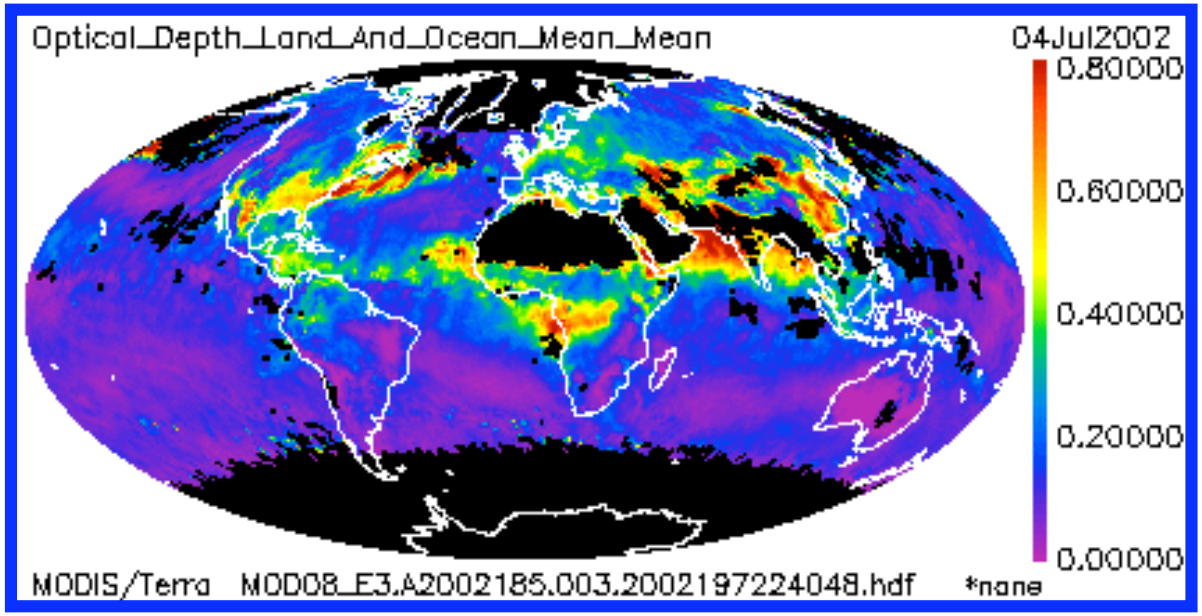


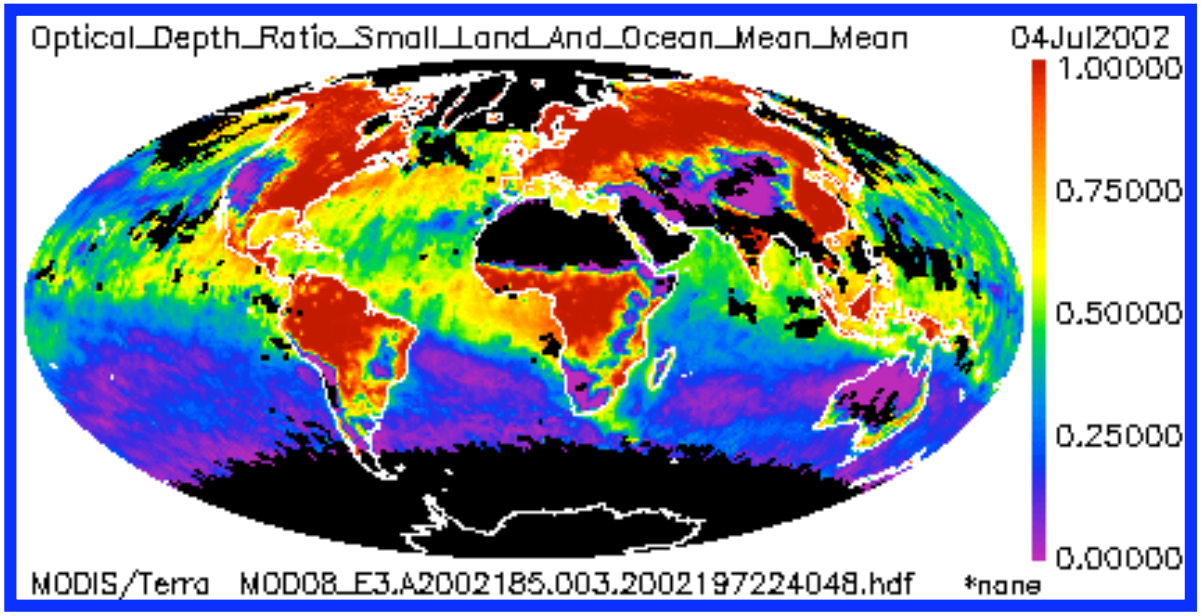
m=1.37



m=1.60

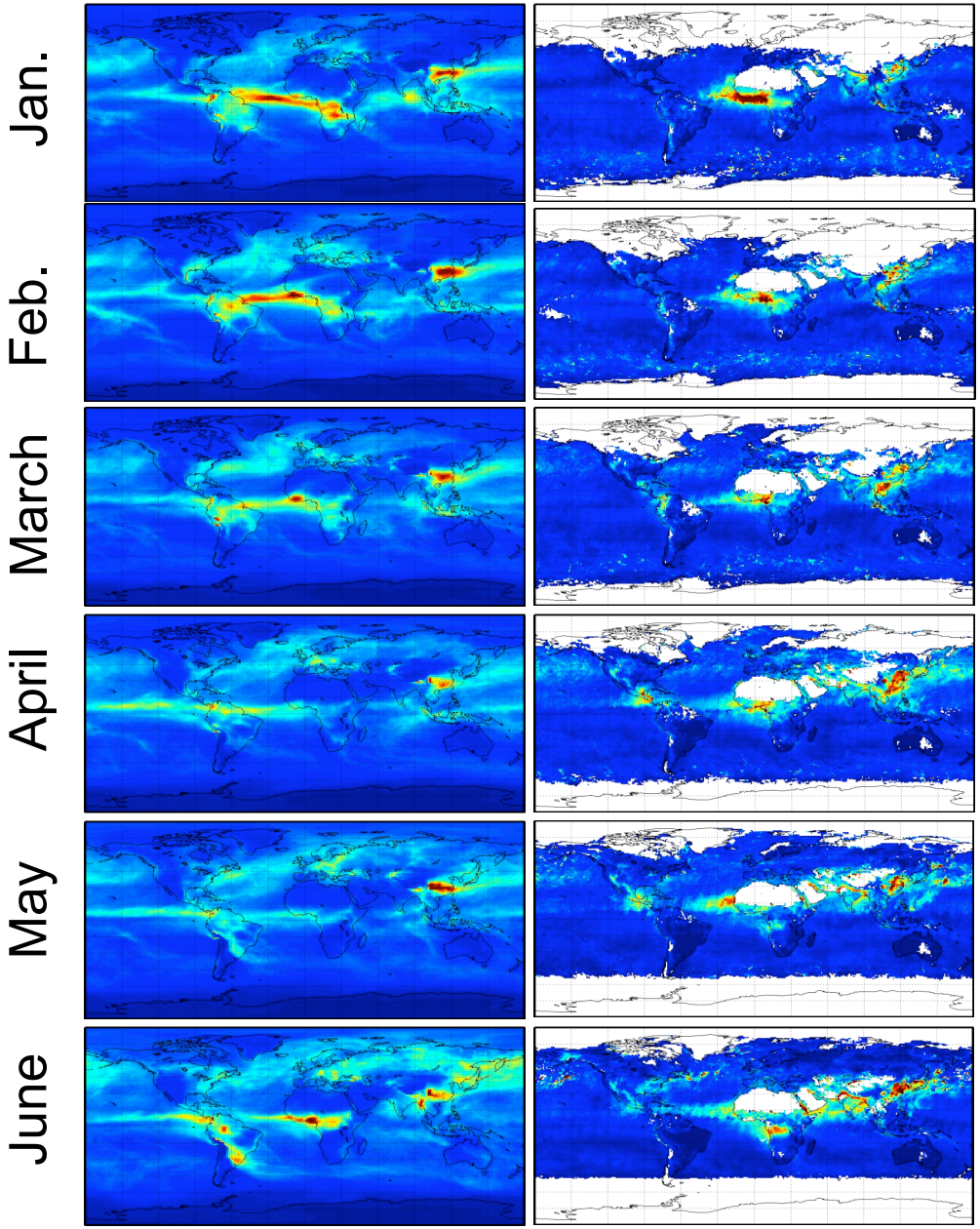
Global Aerosol Retrieval from MODIS





6. Aerosol Data Assimilation in climate modeling

Comparison of AOD estimate from MODIS & Model



Right ◊ AOD MODIS retrieval
Left ◊ AOD model output

Model is GEM-AQ from York University

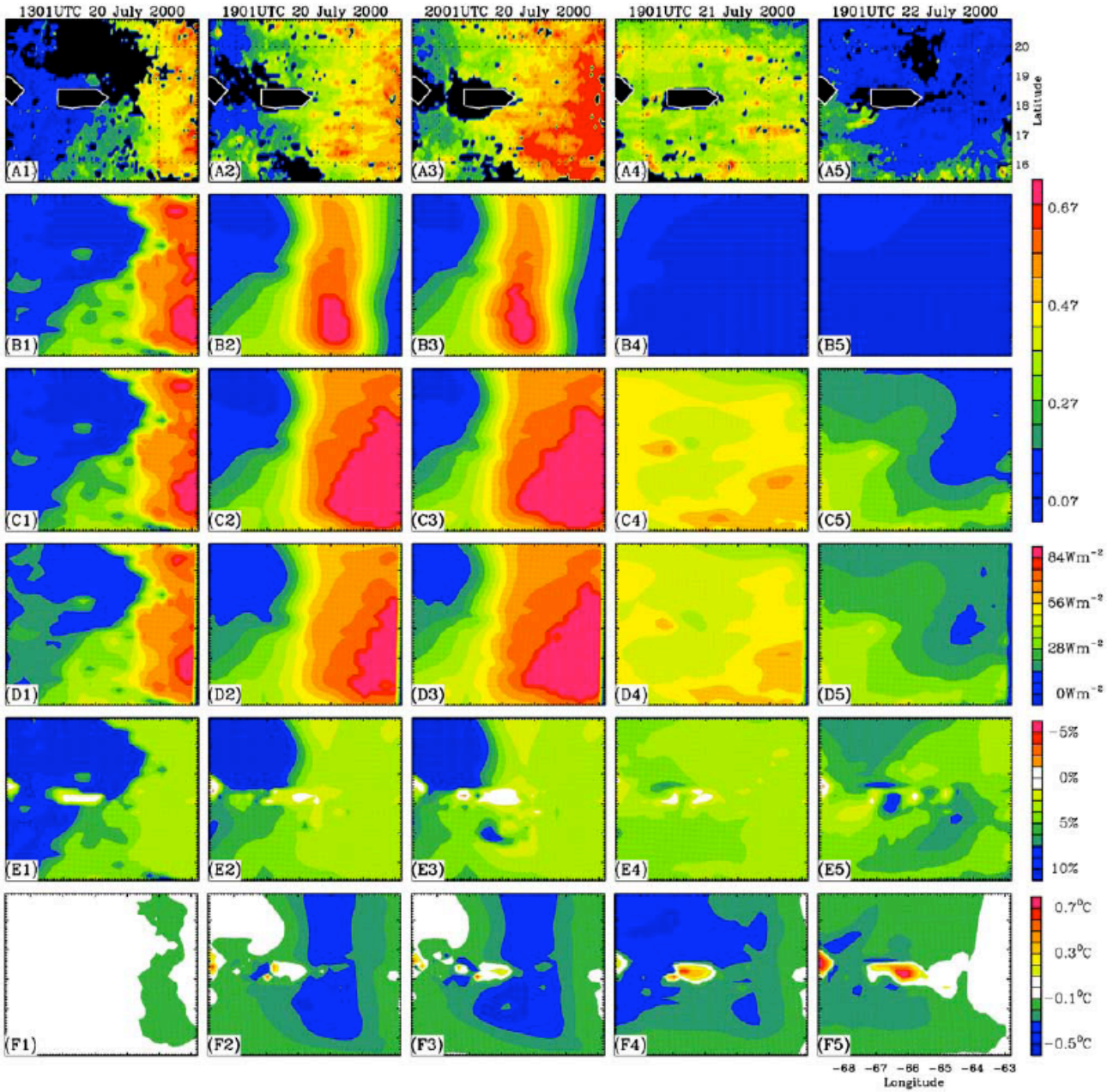
monthly averages for
Jan. to June of 2005

Assimilation of AOD using nudging scheme

Dust AOD retrieved from GOES 8

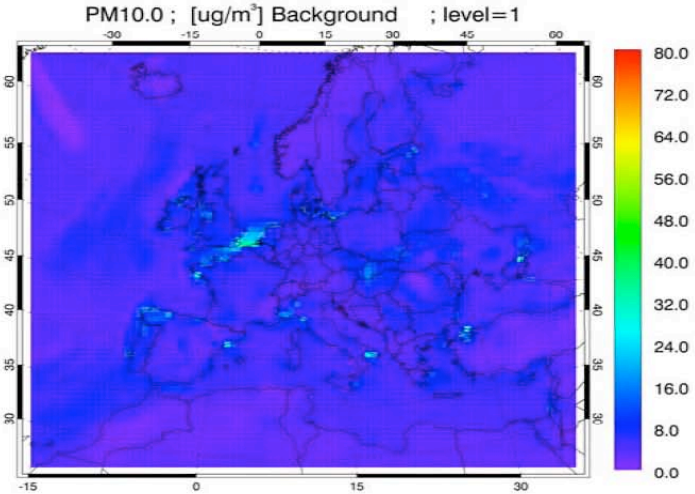
Model results of AOD (from RAMS) without assimilation:

With assimilation:

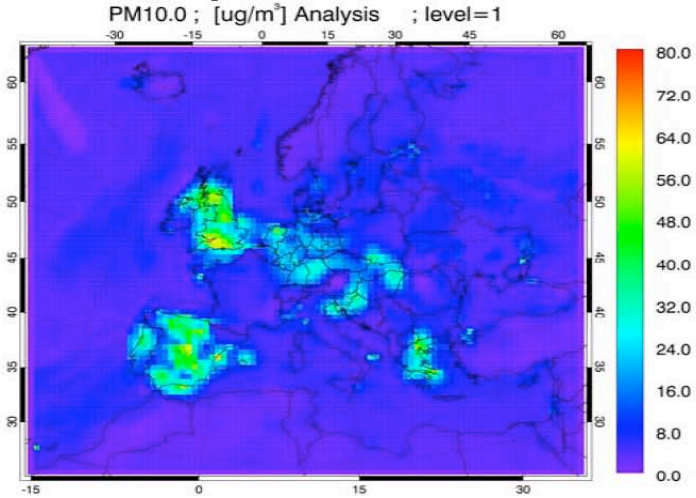


3Dvar aerosol assimilation (14.7.2003) biomass burning case in Spain

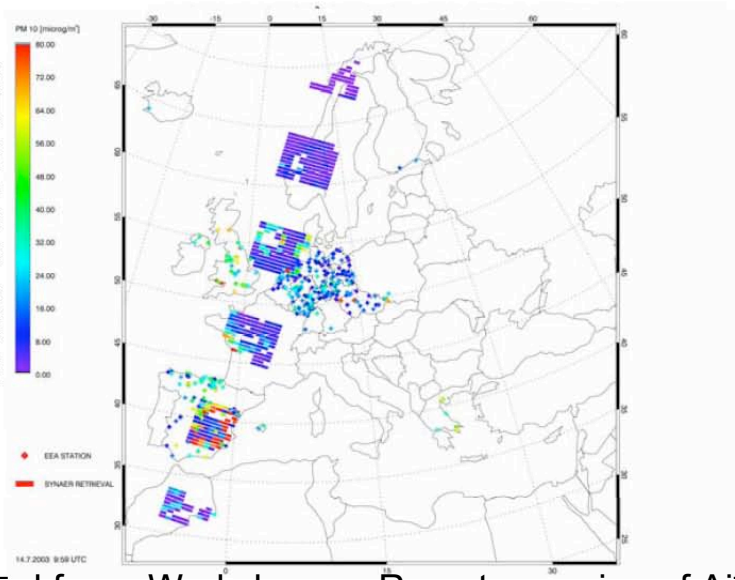
background



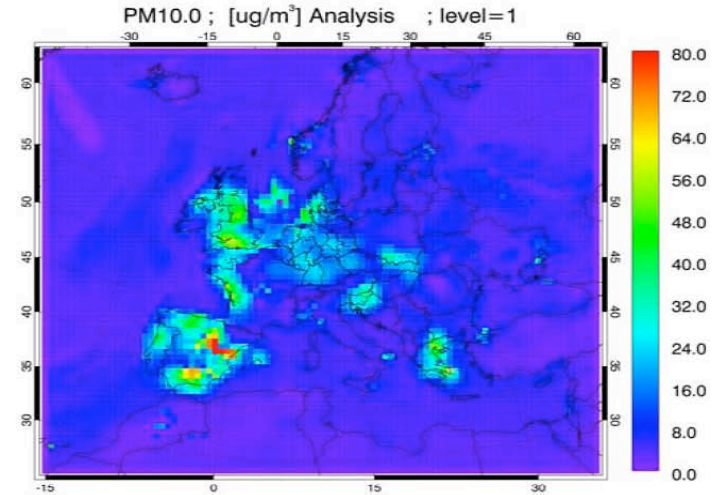
in situ only



in situ & SYNAER



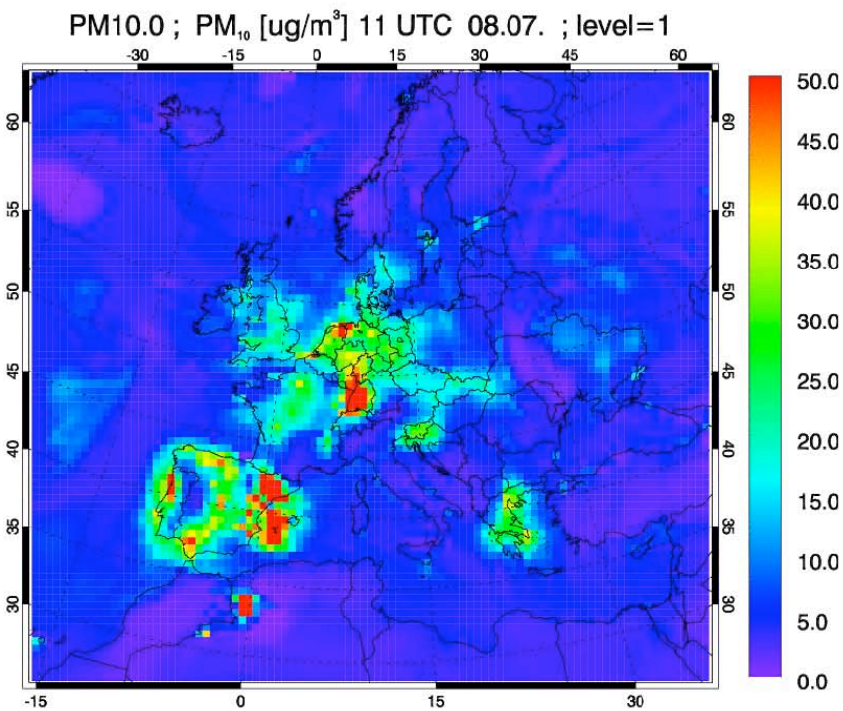
in situ & SYNAER
in situ & SYNAER

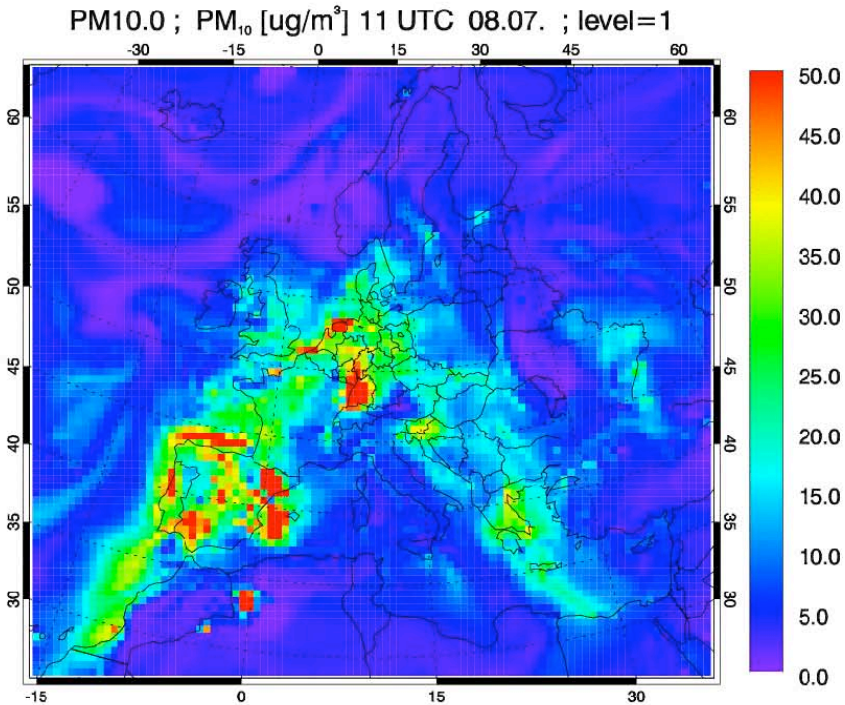


Adapted from: Workshop on Remote sensing of Air Pollution 28.6.2006; University of Cologne Institute for Geophysics and Meteorology with the Rhenish Institute for Environmental Research

Do Aerosol data assimilation effects accumulate?

14 July 2003





No previous assimilation

only 14. July 2003

assimilation on previous days 10 UTC

Accumulation of retrieval information over 14 days

Adapted from: Workshop on Remote sensing of Air Pollution 28.6.2006; University of Cologne Institute for Geophysics and Meteorology with the Rhenish Institute for Environmental Research

Advantages and limitations of using satellite data for aerosol monitoring

Advantages

Spatial coverage is greater than using local station. *due to an ever increasing suite of satellite sensors with different RS strengths (A-train, for example*

Limitations

Available only above surfaces of very low reflectivity (e.g. ocean, wet land or heavy vegetation). *But "Deep-blue" algorithm (Christina Hsu, GSFC) has been developed over bright targets (desert).*
Available only for cloud-free sky.
Limited frequency of satellite overpasses
Uncertainty of retrieval over land or when vertical atmospheric profile has large variations.

TBC