Satellite remote sensing of aerosols & clouds: An introduction

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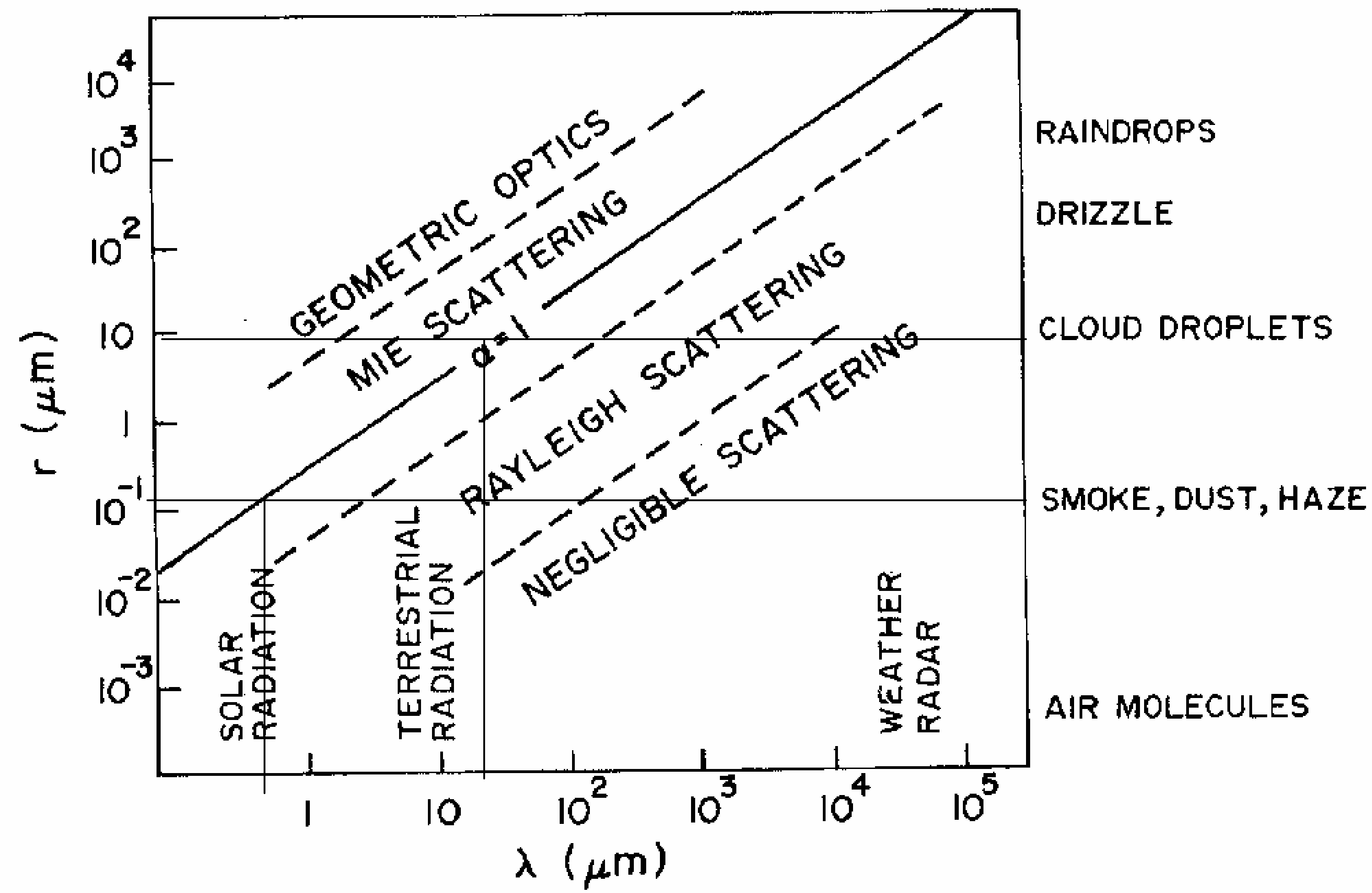
Outline

- Principals in retrieval of aerosols
- Principals in retrieval of water clouds
- Principals in retrieval of ice clouds
- Outstanding issues

Scattering regime



The scattering of solar and terrestrial radiation by atmospheric aerosols and clouds is mostly in the Mie scattering regime.

1 - channel retrieval algorithm

In visible spectrum:

$$I^{\uparrow}(0) = I^{\uparrow}(\tau_s,)T(\tau_s,0) + \int_{\tau_s}^{0} J^{\uparrow}(\tau)T(\tau,0)\,d\tau$$

$$J^{\uparrow}(\tau) = (1-\varpi)\cancel{B_\lambda(\tau)} + \frac{\varpi}{4\pi}\int_{\Omega} I_\lambda(\tau)P(\Omega)\,d\Omega$$

No Emission

Surface properties

Aerosol properties

Refractive index, Size, Shape, etc

Under single scattering assumption and if surface reflectance is low:

$$Define \quad R = \frac{\pi I^{\uparrow}(0)}{F_0\mu_0}$$

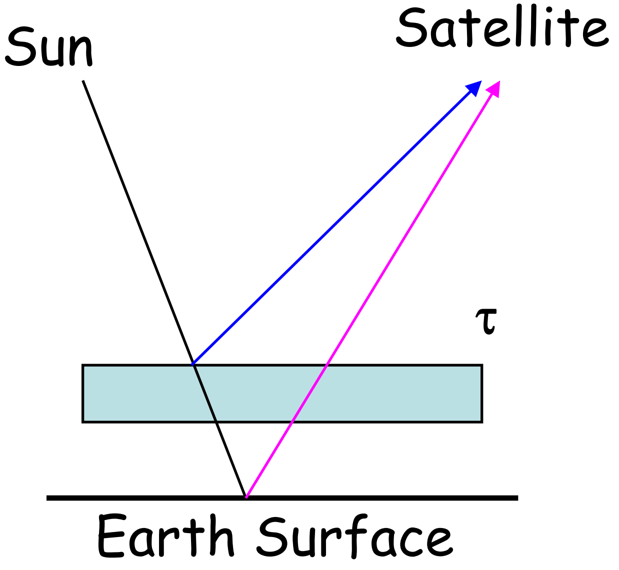
$$R_{sat} = R_{sfc} + \frac{\varpi\tau}{4\mu\mu_0}P(\Omega)$$

Key factors for the retrieval of AOT : ω, P(θ), and R_{sfc}

Satellite retrieval of AOT in visible spectrum

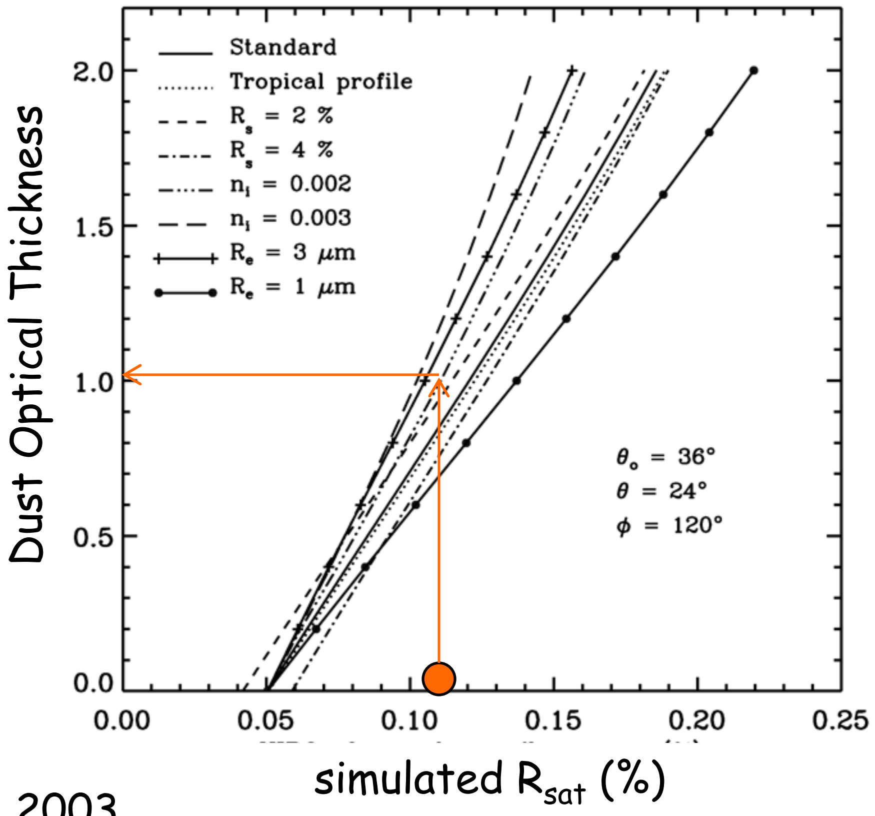
single scattering, low R_{sfc} (<0.1)

$$R_{sat} = R_{sfc} + \frac{\omega \tau P(\theta)}{4\mu\mu_0}$$



Key factors : ω, P(θ), and R_{sfc}

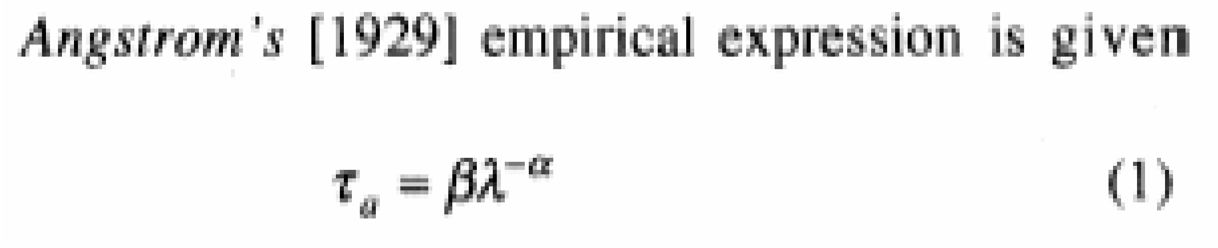
Refractive index, Size, Shape, etc



Liu, Wang & Christopher, Int. J. Rem. Sen.,2003

2 – channel retrieval algorithm

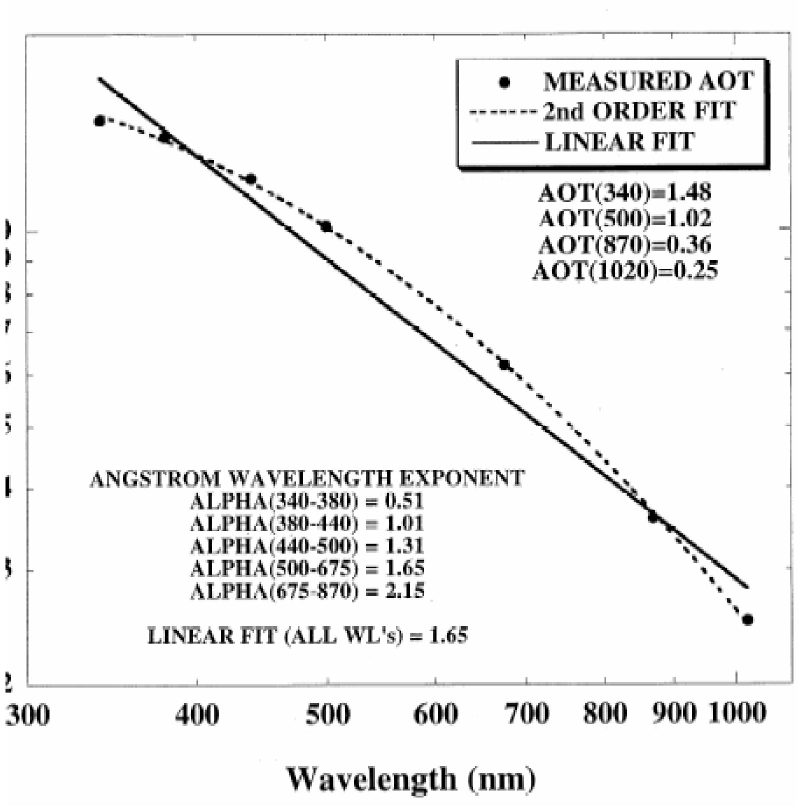
Wavelength dependence can be used as an indicator to the aerosol size



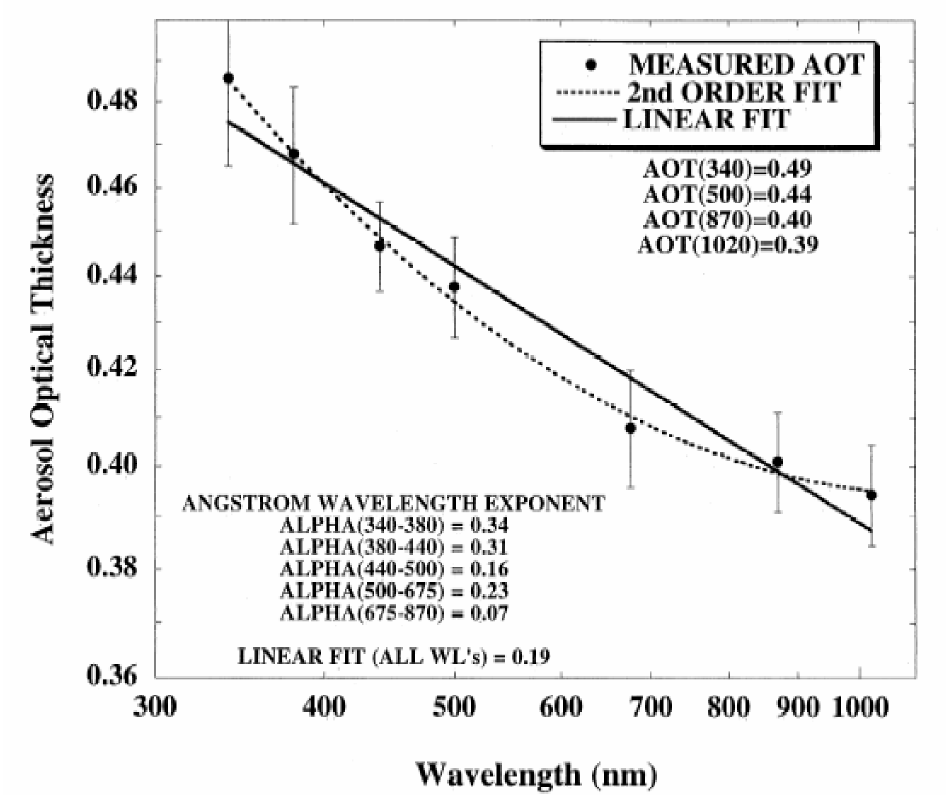
Angstrom's [1929] empirical expression is given

$$\tau_a = \beta\lambda^{-\alpha} \qquad (1)$$

Eck et al., JGR, 1999



Urban aerosols in Washing DC

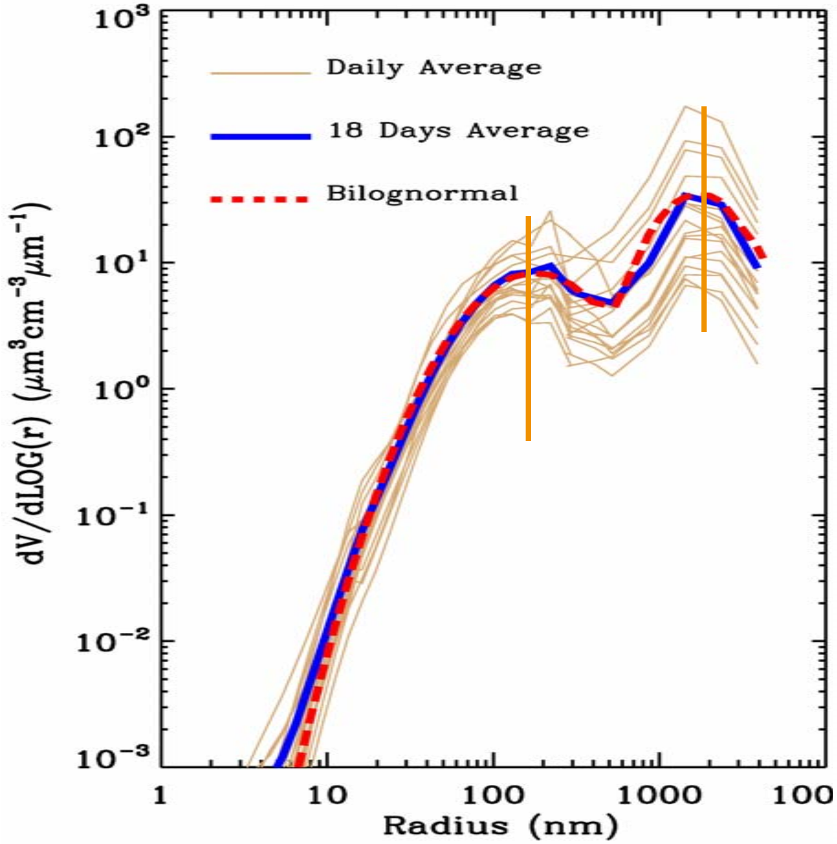


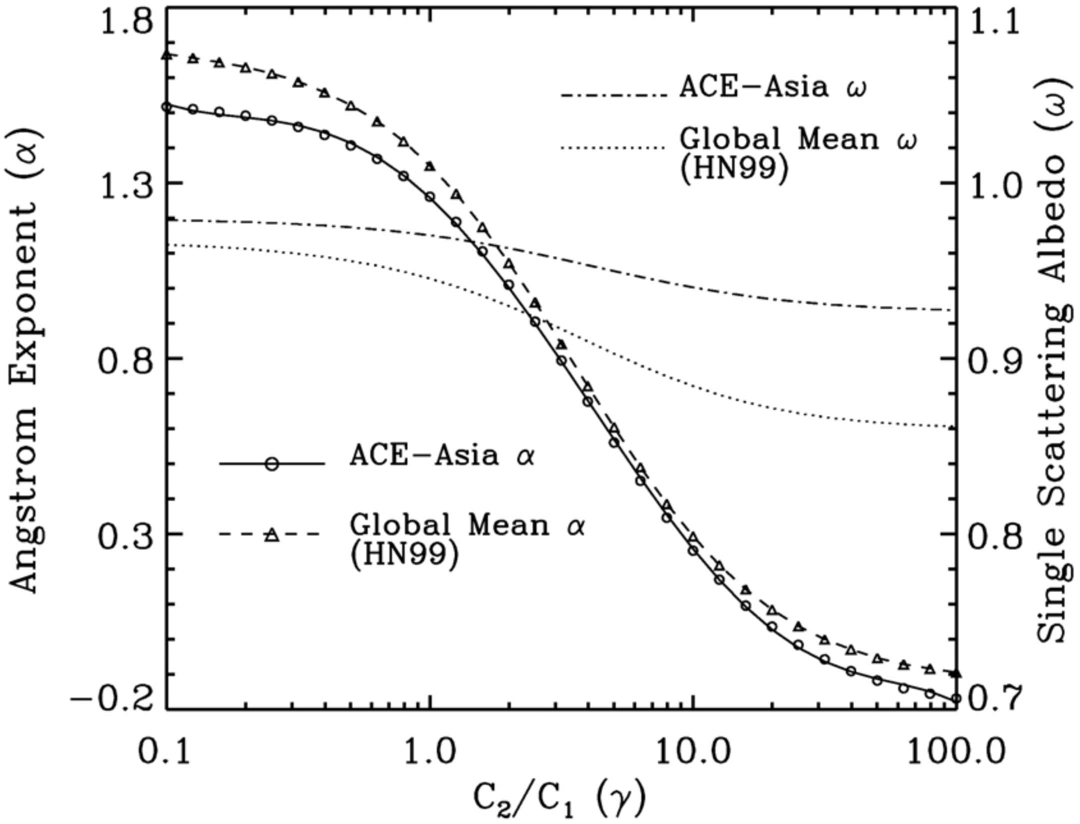
Dust aerosols in Mongolia

Small vs. big size mode fraction

$$\frac{dV}{d\log_{10} r} = \sum_{n=1}^{2} C_n \exp\left[-\frac{1}{2}\left(\frac{\log_{10} r - \log_{10} r_{vn}}{\log_{10} \sigma_n}\right)^2\right]$$

Angstrom exponent can provide information for small/big size





Challenges: surface reflectance

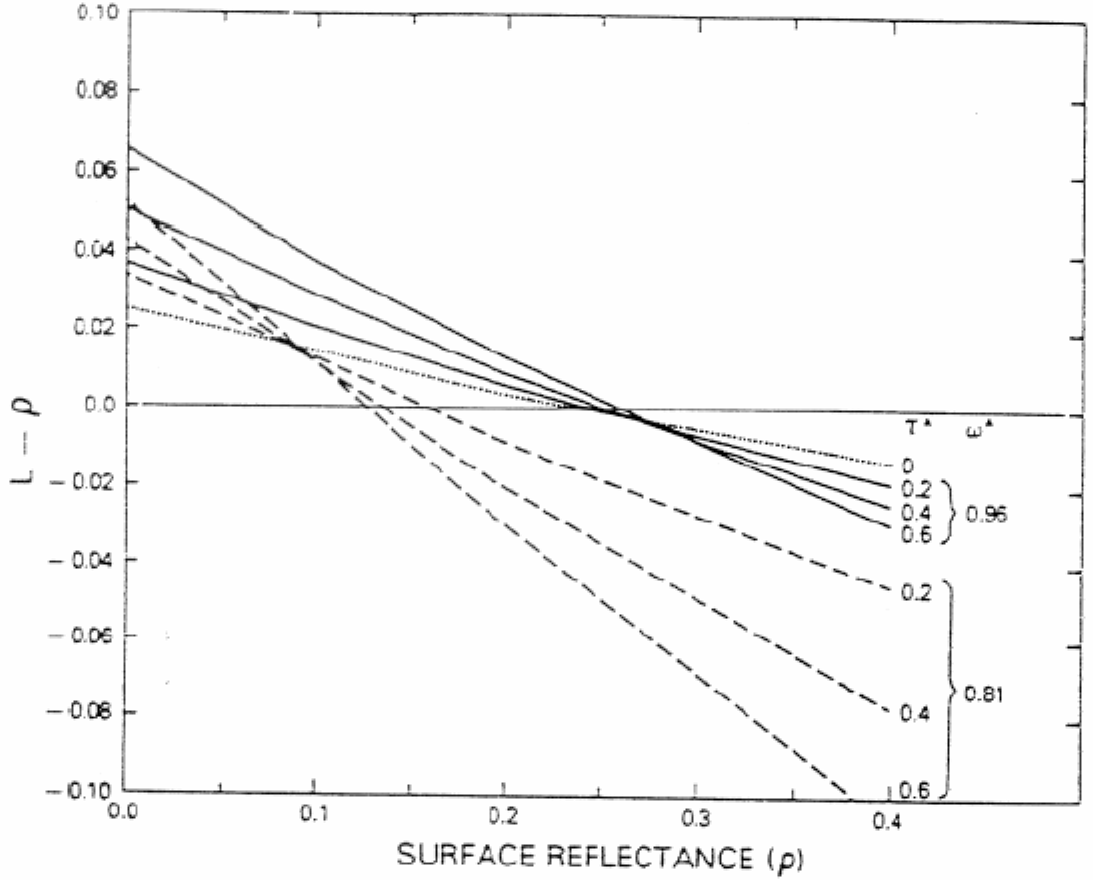
$$R_{sat} = R_{sfc} + \frac{\omega\tau P(\theta)}{4\mu\mu_0}$$ Only valid when Rsfc is small.

Reflectance over ocean is low and relatively homogenous.

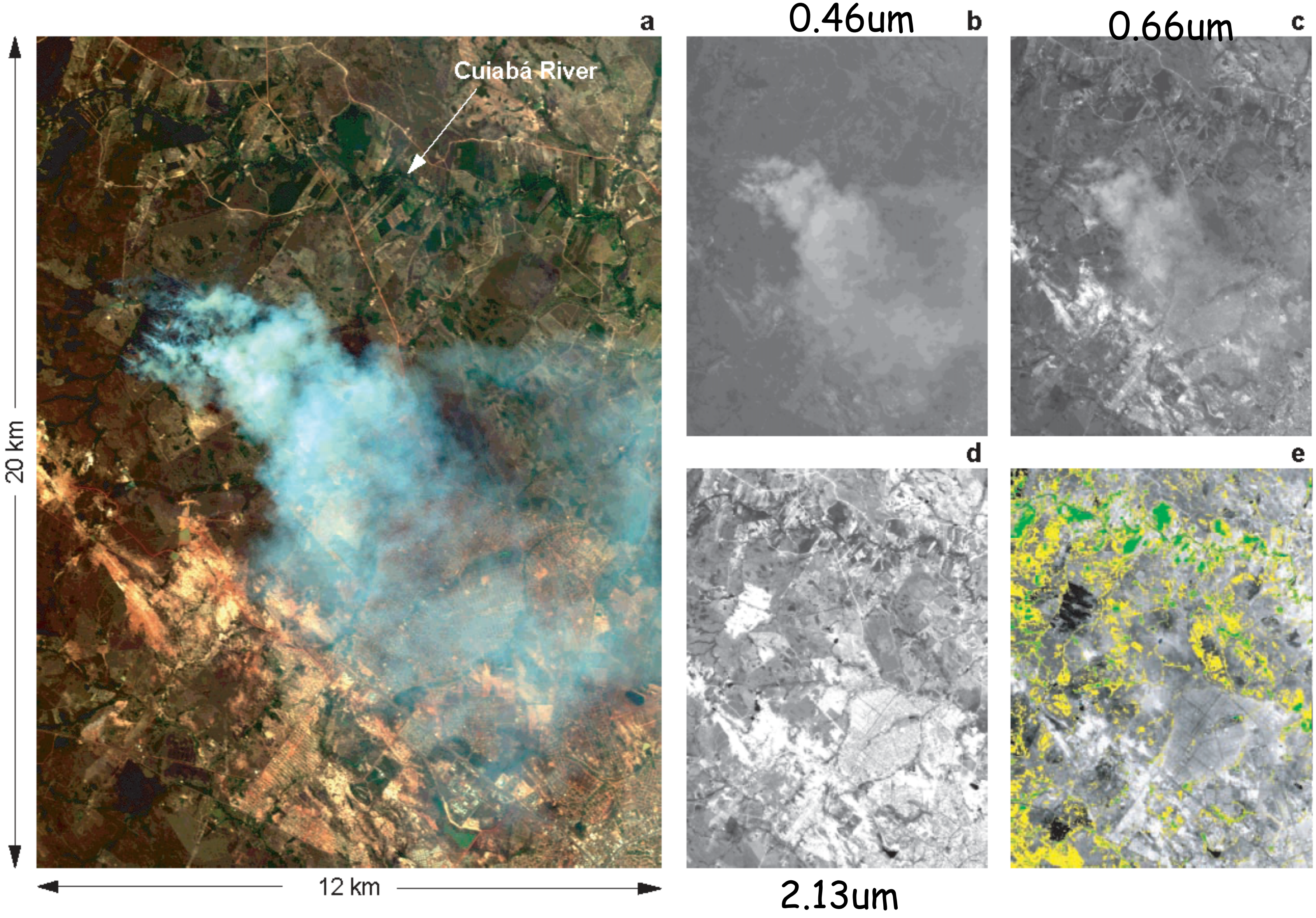
Larger uncertainties over land.

For small particles:

Kaufman and Fraser, 1985



Smoke signal is not in NIR



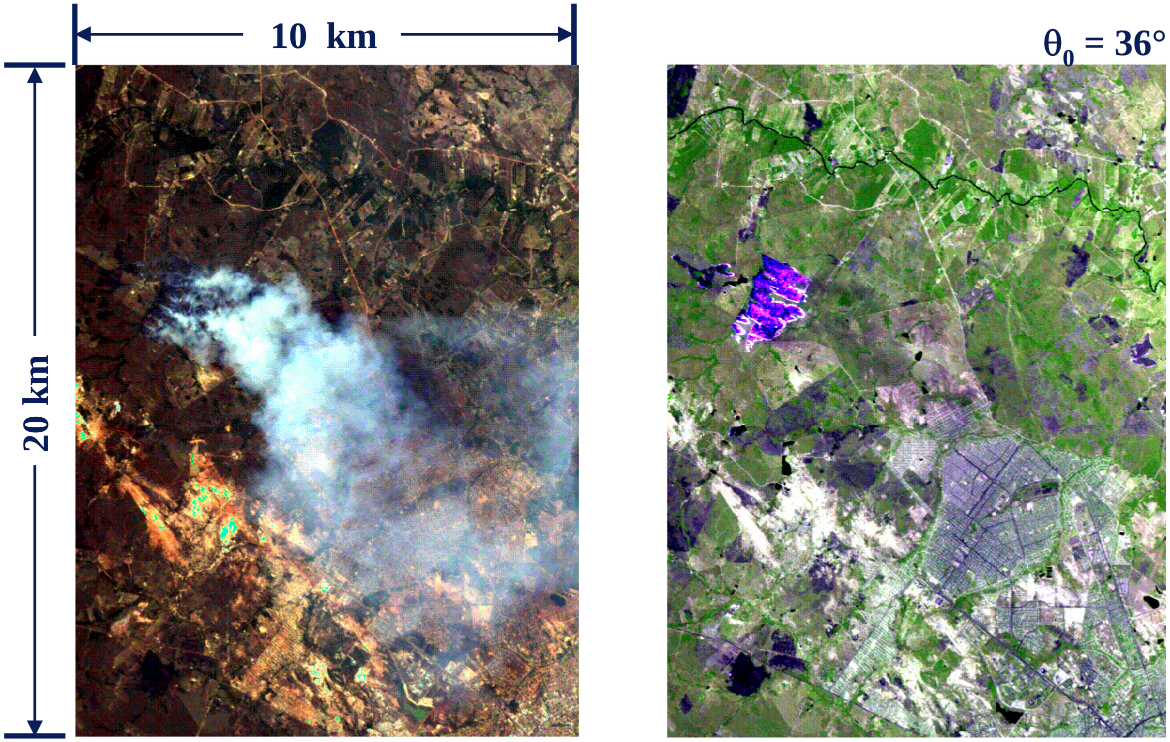
King et al., BAMS, 1999

Aerosol Effects on Reflected Solar Radiation over Land

Biomass burning

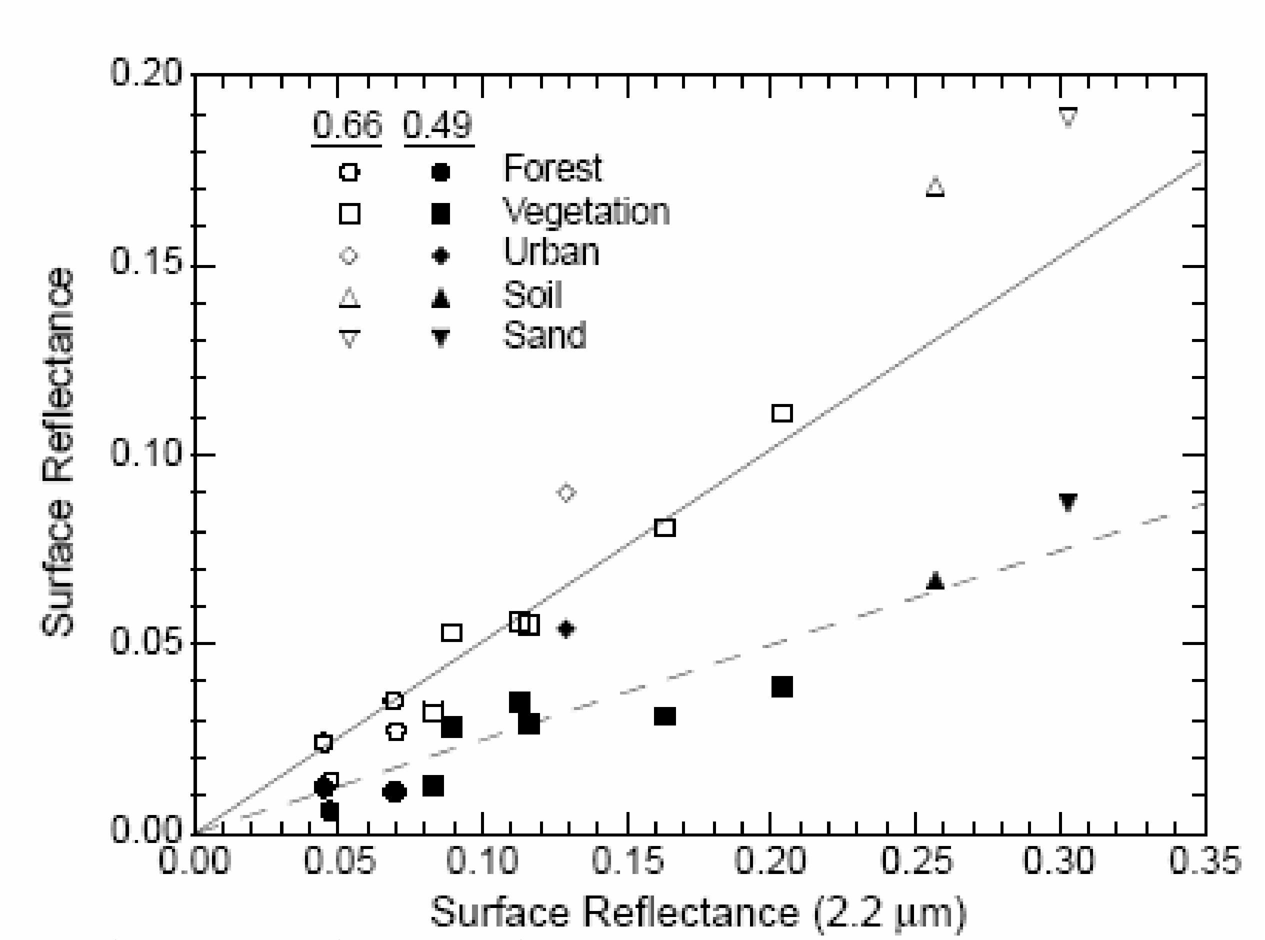
Cuiabá, Brazil (August 25, 1995)

R = 0.66 μm
G = 0.55 μm
B = 0.47 μm



R = 1.65 μm
G = 1.2 μm
B = 2.1 μm

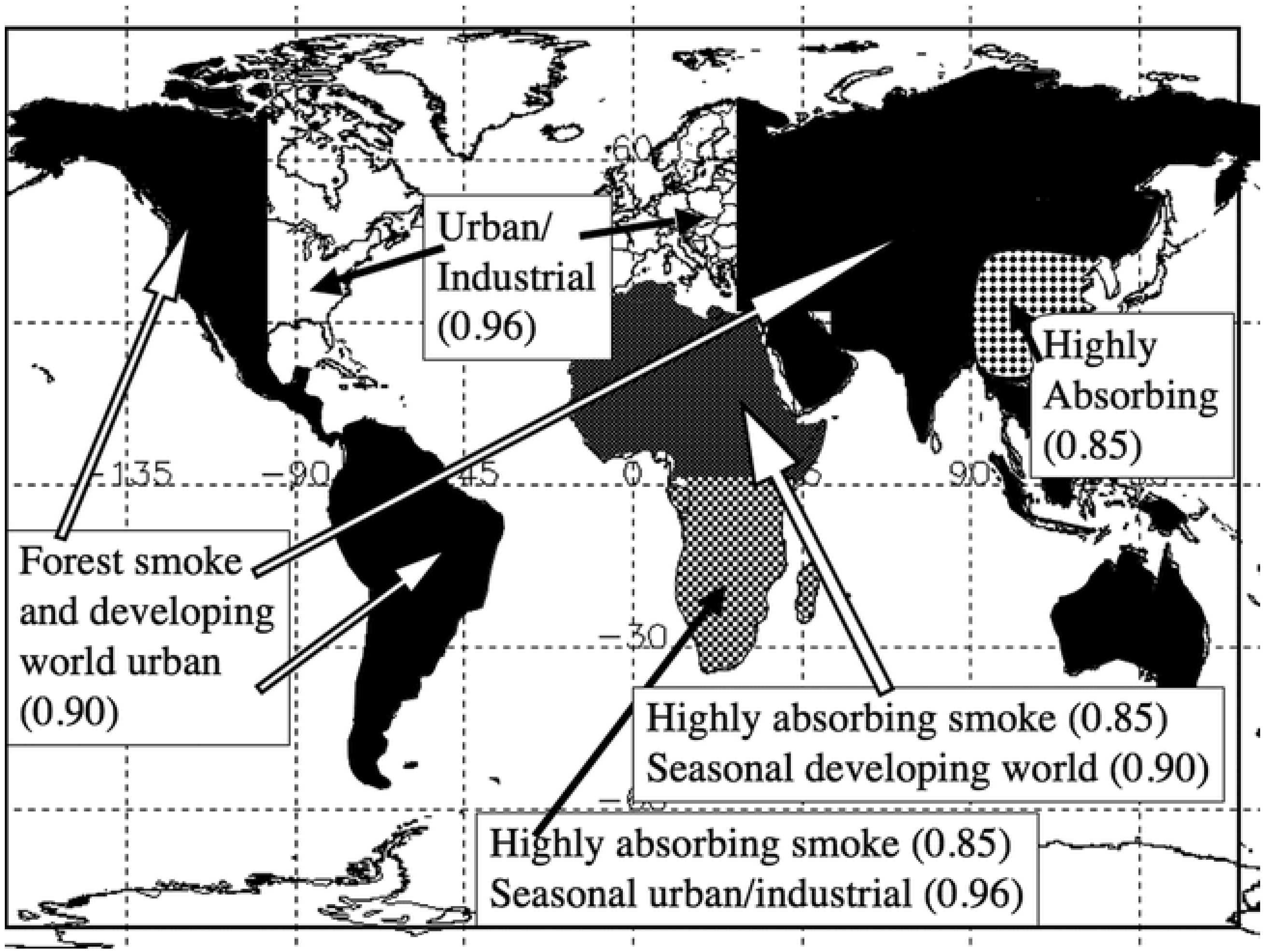
Using NIR reflectance to derive VIS



$$A_g(0.47\ \mu m) = 0.5\ A_g(0.66\ \mu m)$$
$$= 0.25 A_g(2.1\ \mu m)$$

How aerosol optical properties are calculated?

Remer et al., 2005



Urban/ Industrial (0.96)

Highly Absorbing (0.85)

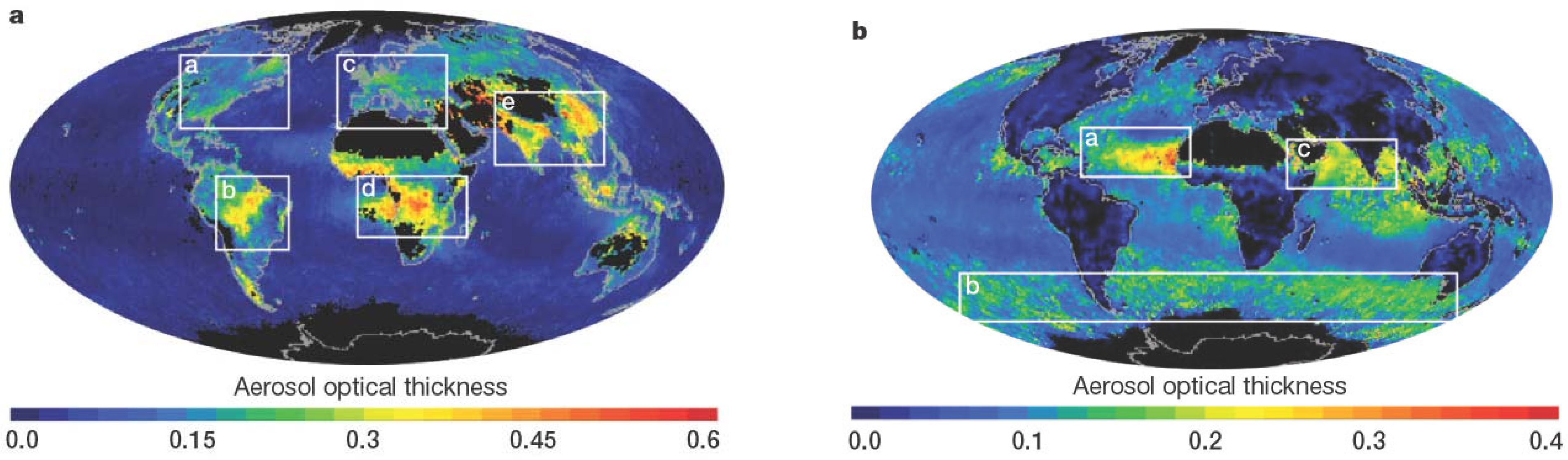
Forest smoke and developing world urban (0.90)

Highly absorbing smoke (0.85)
Seasonal developing world (0.90)

Highly absorbing smoke (0.85)
Seasonal urban/industrial (0.96)

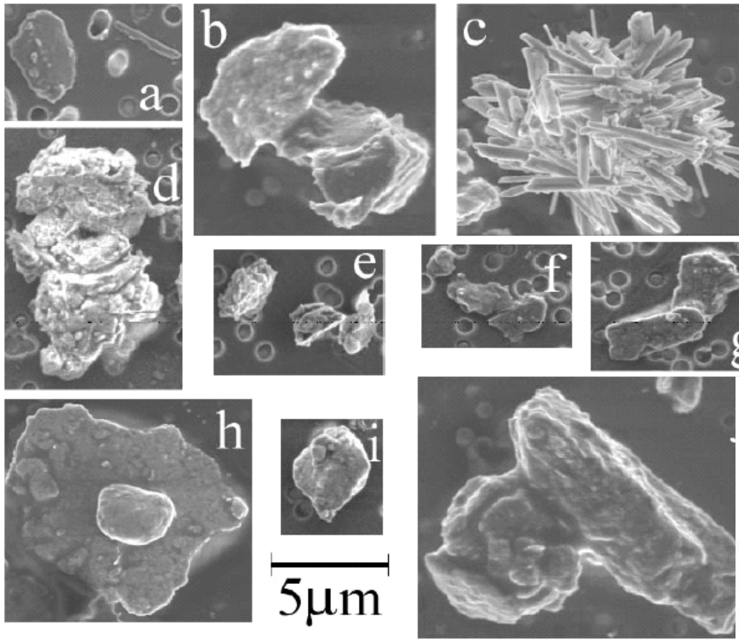
The selection of aerosol optical model primarily is primarily based on geographical locations.

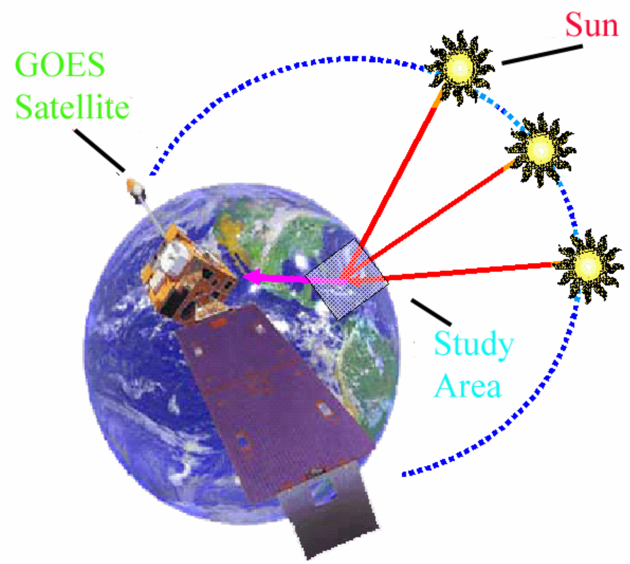
MODIS AOT

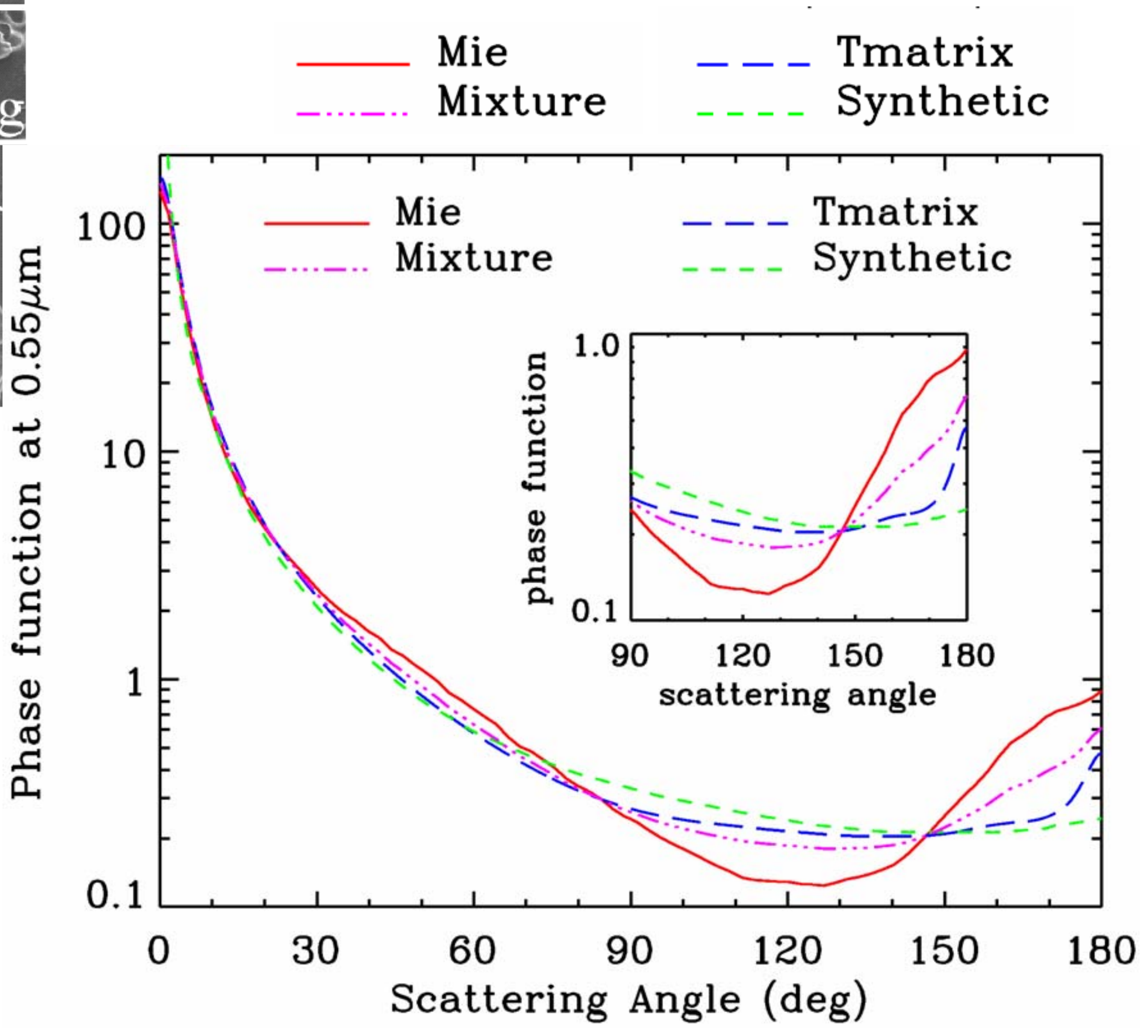


MODIS AOT. (a) fine mode AOT (b) coarse mode AOT, September 2000

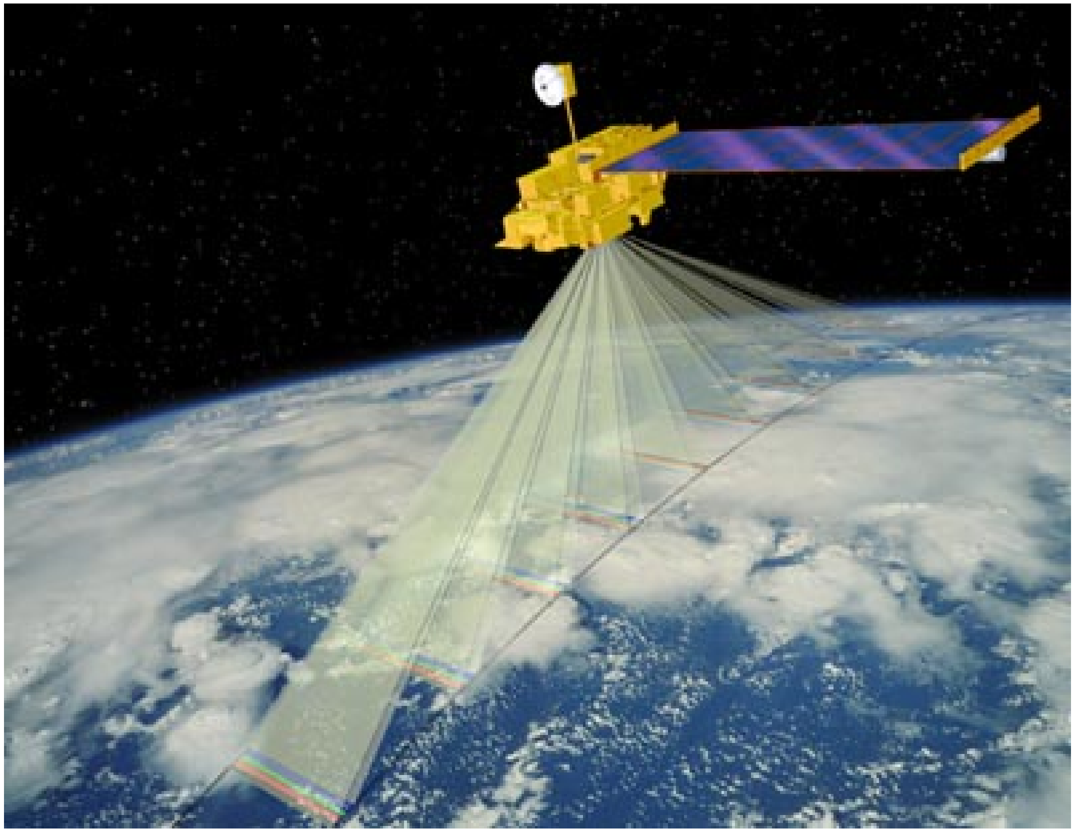
Challenges: Aerosol optical property



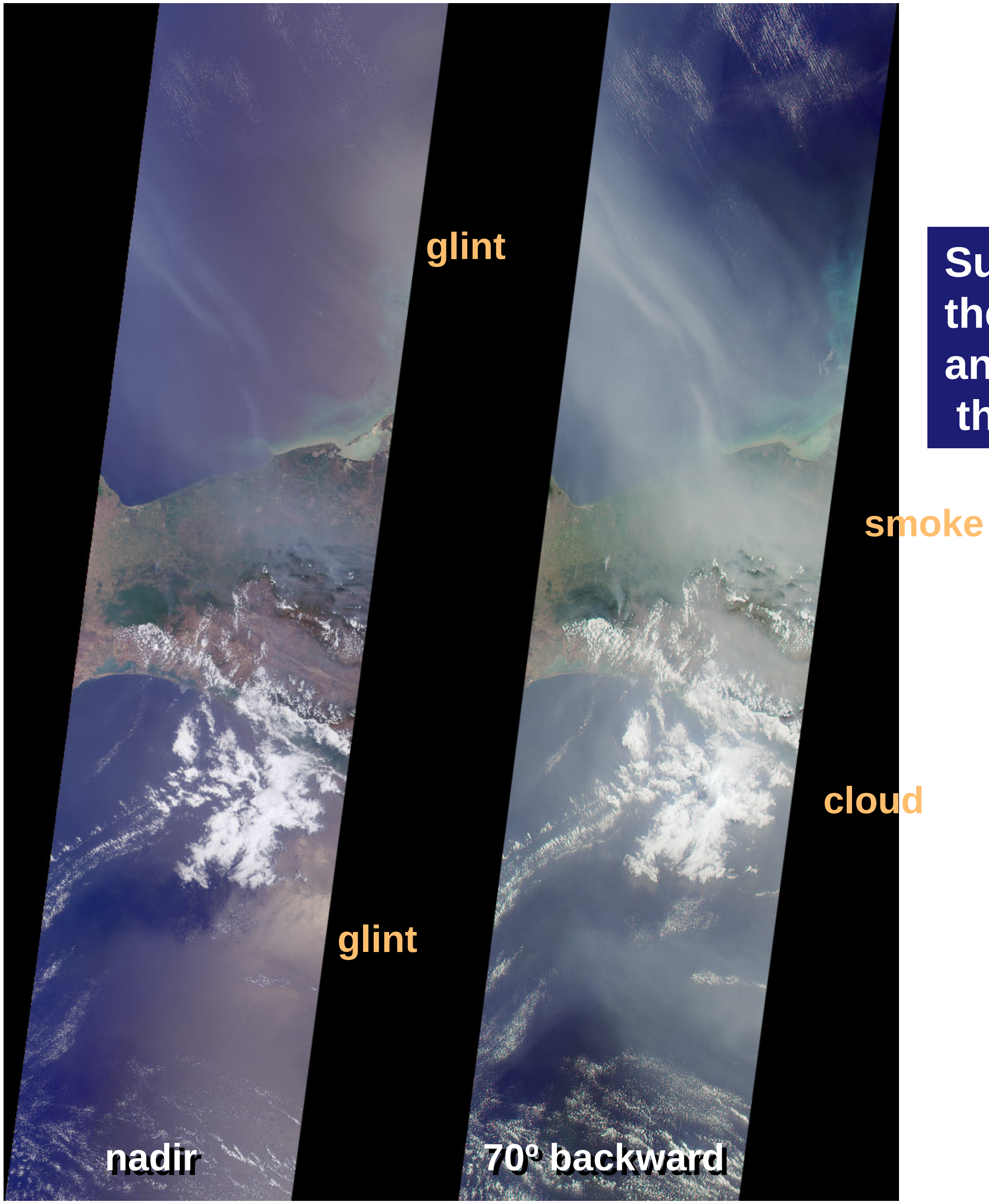




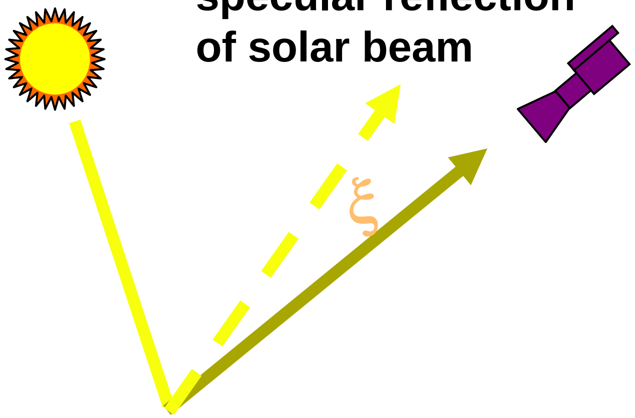
MISR Imaging SpectroRadiometer MISR



Avoiding sunglint



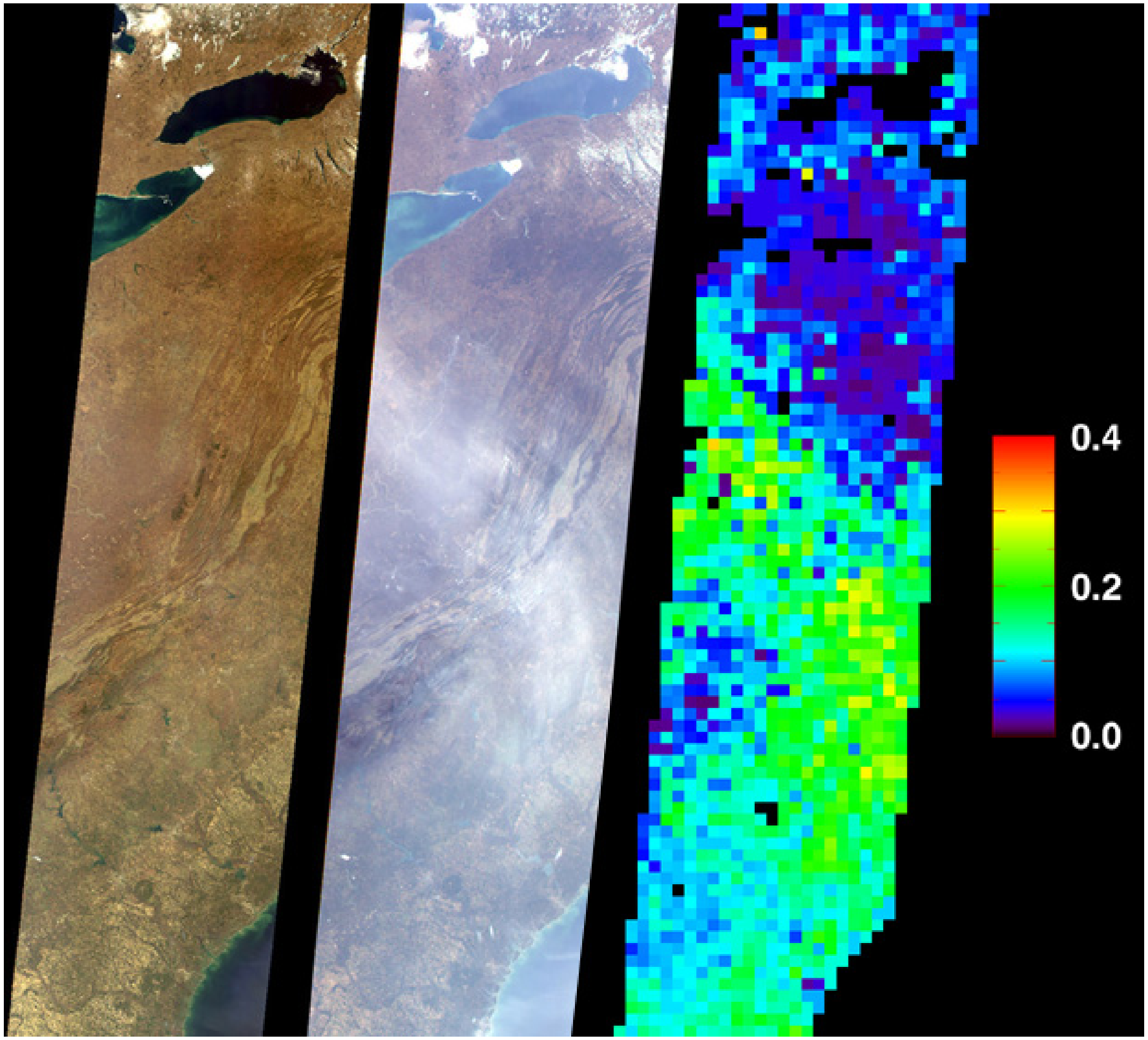
Sunglint over water invalidates the assumption of a dark surface, and multiple cameras provide the flexibility to avoid this



specular reflection of solar beam

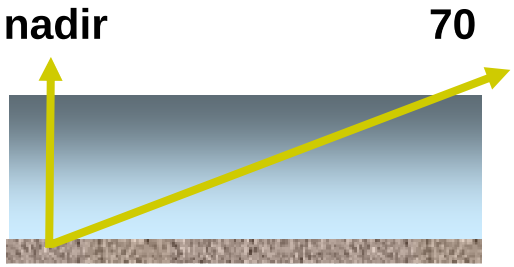
MISR aerosol retrievals require glitter avoidance of at least 40º

Enhancing sensitivity to thin aerosols



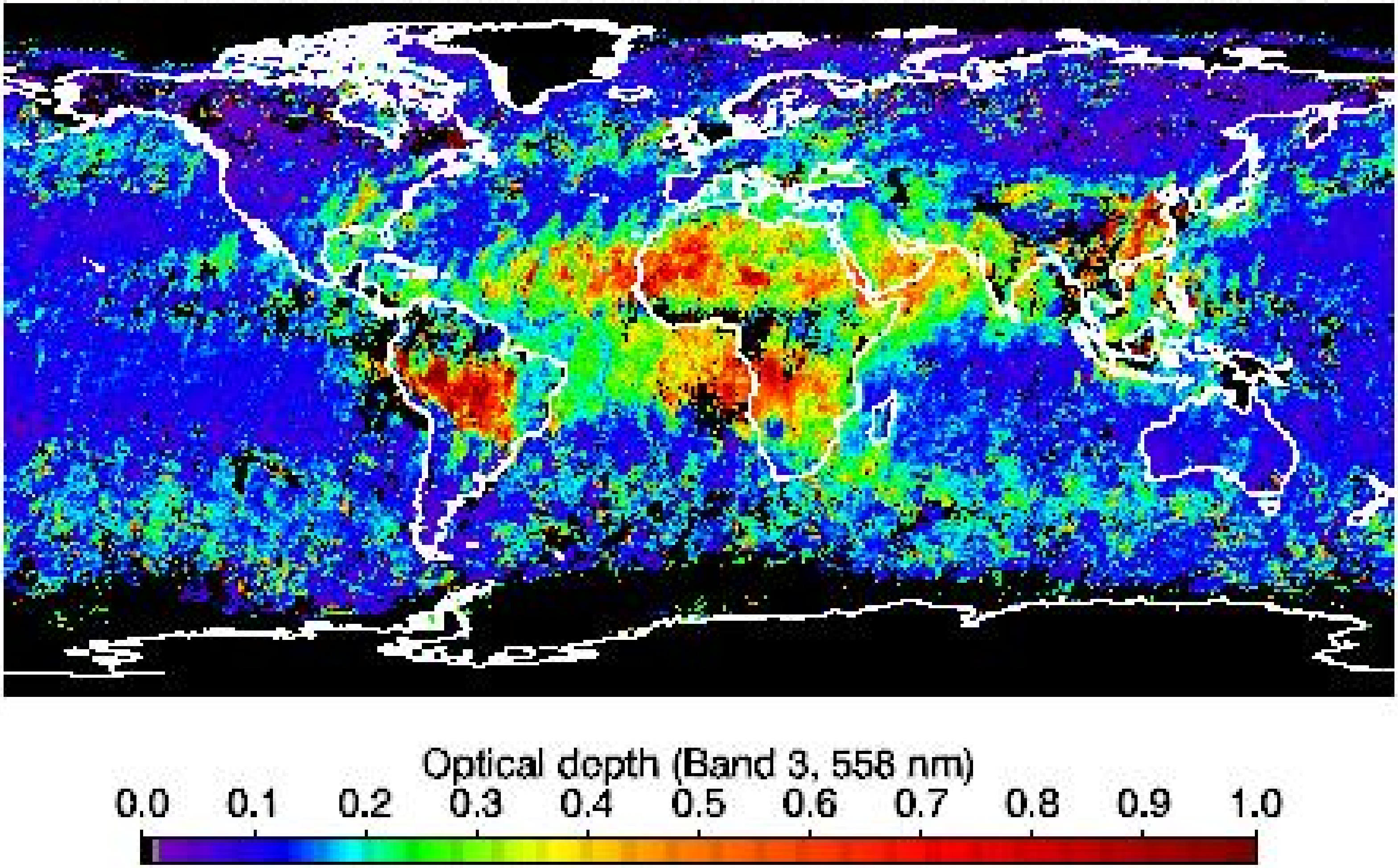
Thin haze over land is difficult to detect in the nadir view due to the brightness of the land surface

The longer atmospheric path length enhances the haze path radiance



Optical depth September 2005 F06_0017

Summarizes L2 AS_AEROSOL, RegMeanSpectralOptDepth field F09_0017, 0.5 deg res



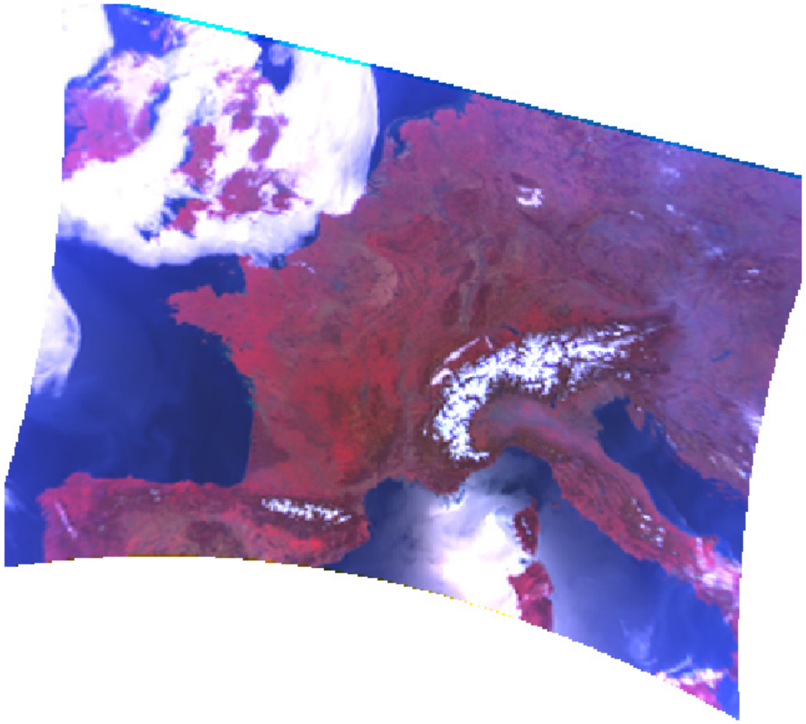
Radiance and Polarization Measurements from POLDER

Western Europe

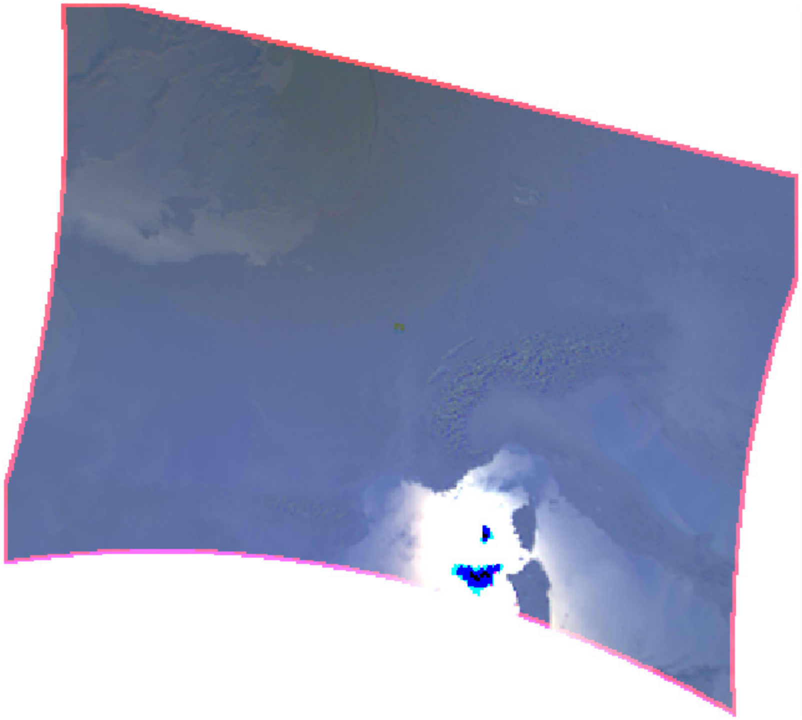
March 10, 1997

R = 0.865 µm
G = 0.670 µm
B = 0.443 µm

Radiance



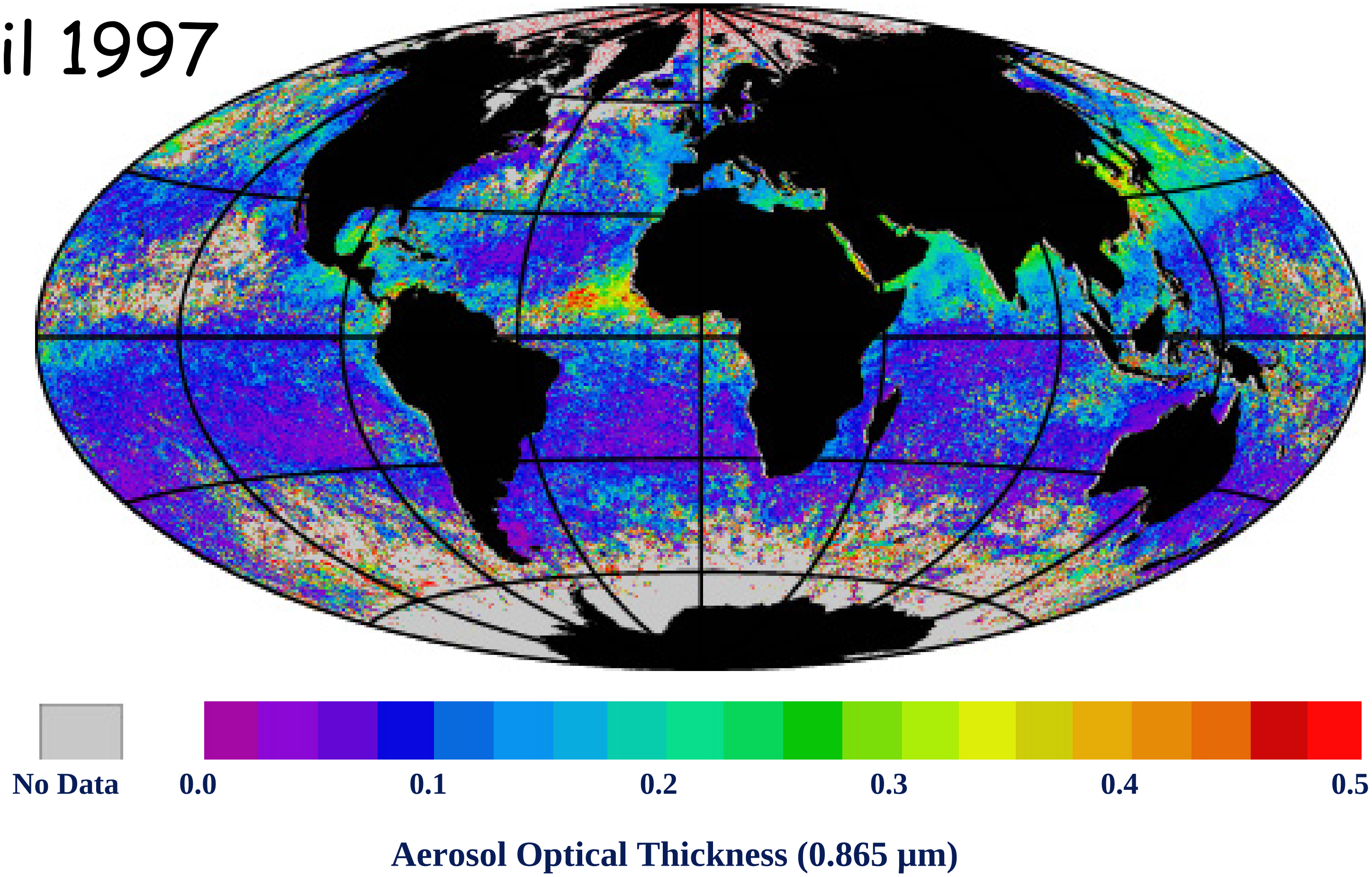
Polarization



Notice the land

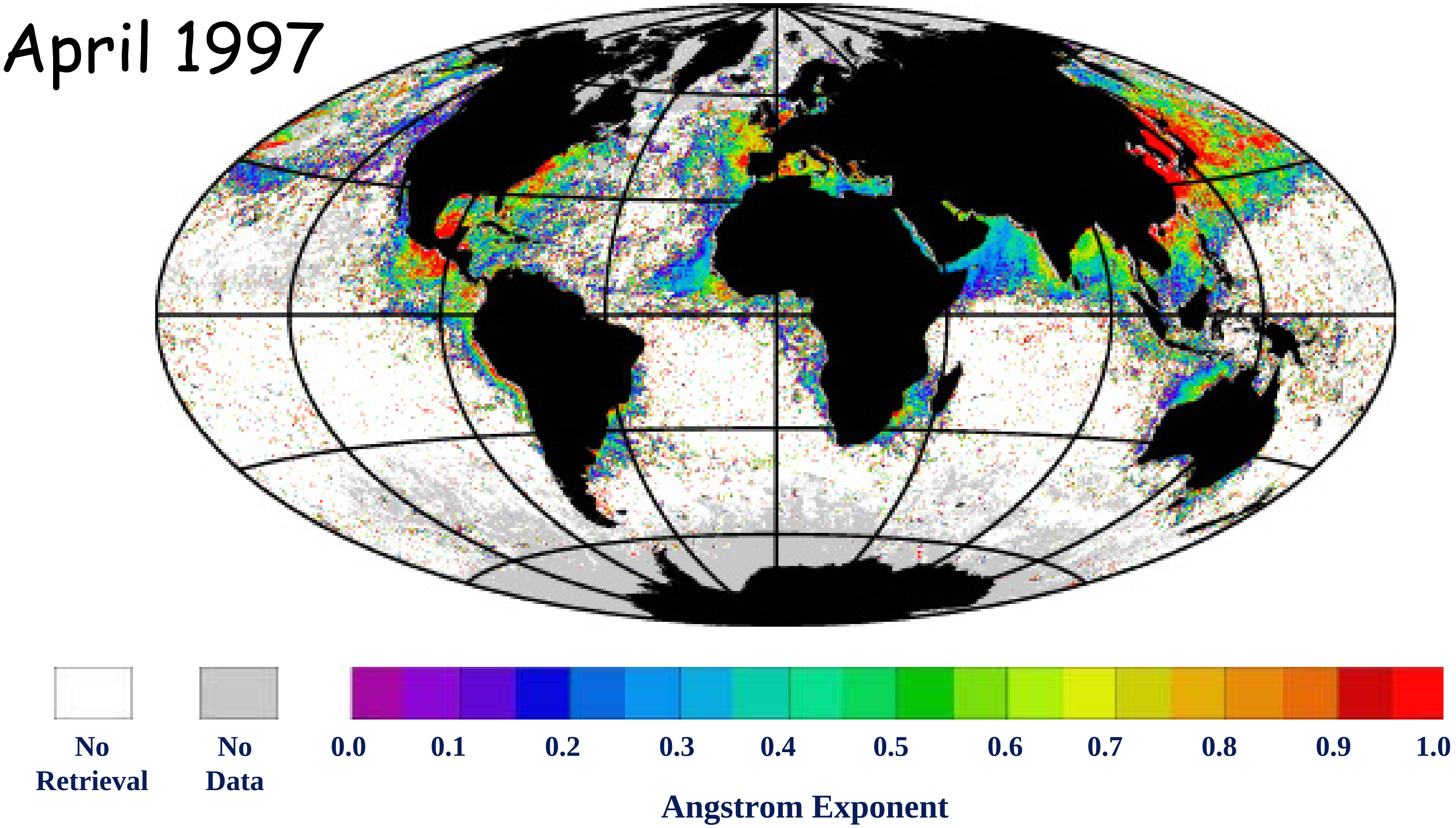
Aerosol Optical Thickness

POLDER
April 1997



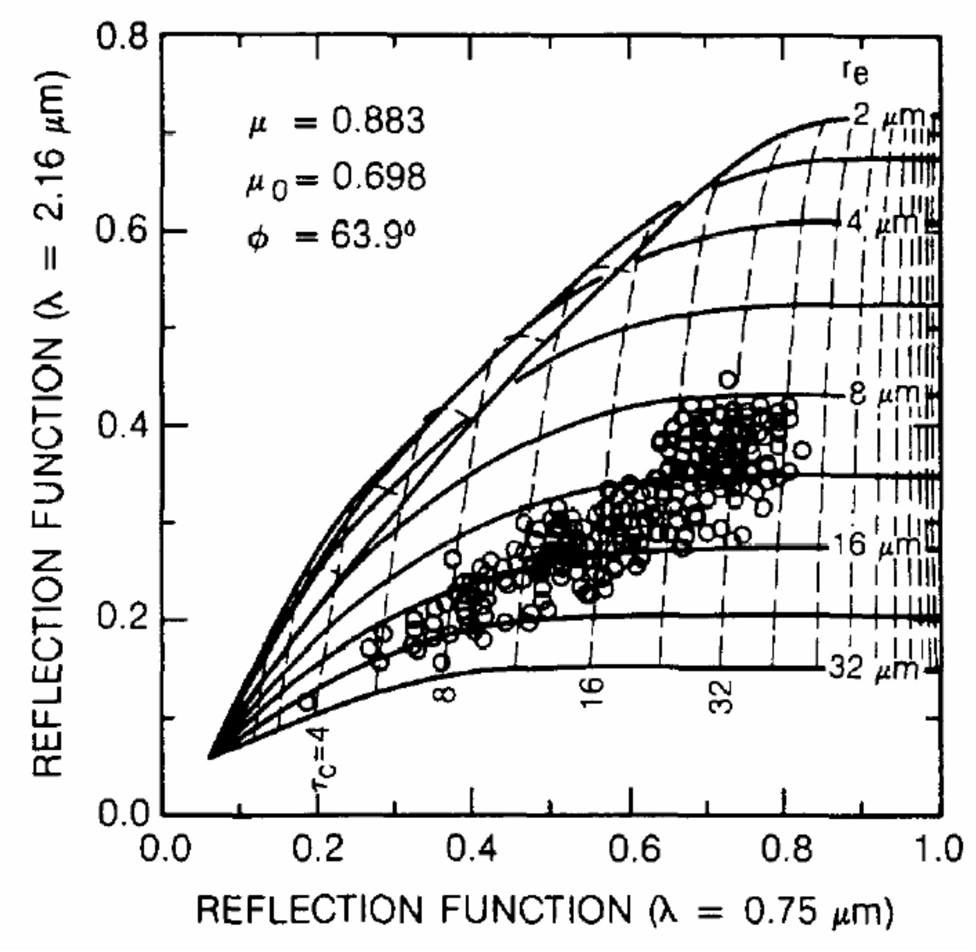
Ångström Exponent

POLDER
April 1997



Remote sensing of water clouds

Determination of the Optical Thickness and Effective Particle Radius of Clouds



NAKAJIMA & King, 1990

Solar reflectance technique:
Principles:

- The reflection function of a nonabsorbing band is primarily a function of optical depth.

- The reflection function of a near-IR absorbing band is primarily a function of effective radius.

Why choose the specific near IR and VIS channels?

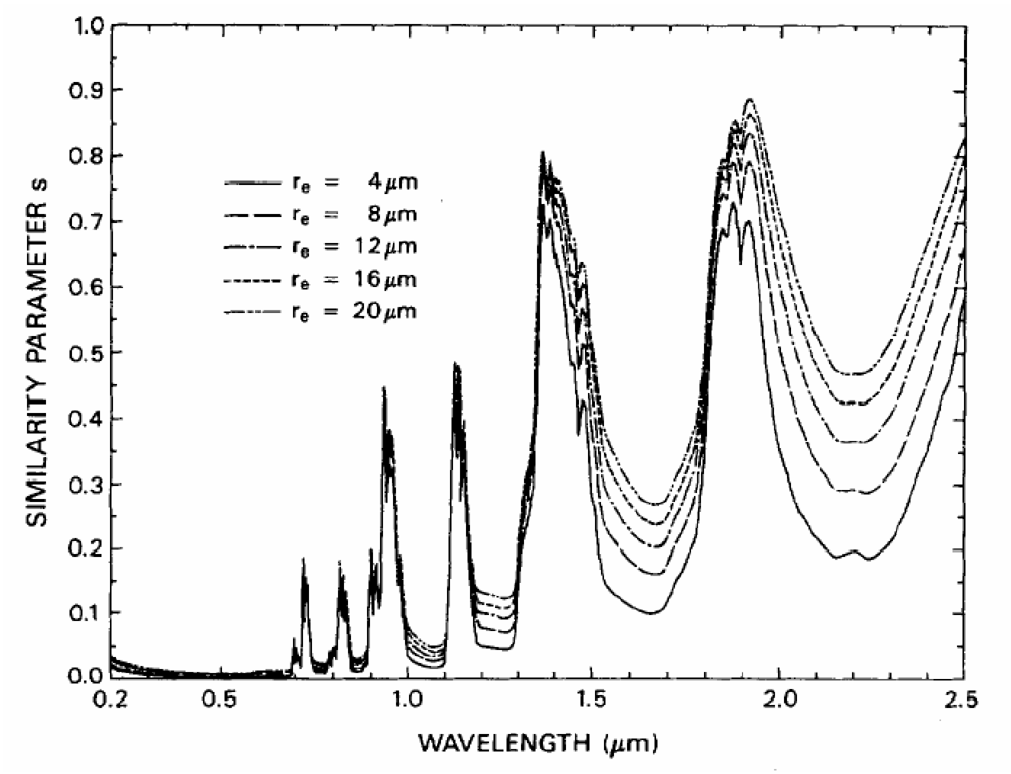
- These channels (0.75, 1.64, 2.16 μm) are selected because they are outside the water vapor and oxygen absorption bands.

$$R(\tau_c; \mu, \mu_0, \phi) = R_\infty(\mu, \mu_0, \phi) - \frac{m[(1 - A_g A^*)l - A_g m n^2]K(\mu)K(\mu_0)e^{-2k\tau_c}}{[(1 - A_g A^*)(1 - l^2 e^{-2k\tau_c}) + A_g m n^2 l e^{-2k\tau_c}]}$$

- *A** the spherical albedo of a semi-infinite atmosphere, and m, *n* and I constants. All five asymptotic constants that appear in this expression [A*, *m,* n, 1 and *k/(* 1 - g)] are strongly dependent on the single scattering albedo ω_0, with a somewhat weaker dependence on g.

These constants can be well represented by a function of a similarity parameter s, defined by

$$s = \left(\frac{1 - \omega_0}{1 - \omega_0 g}\right)^{1/2}$$



(Nakajima & King, 1990)

Calculation of liquid water path

$$\begin{aligned}
\tau &= \int Q_e \pi r^2 n(r) dr \Delta h \\
&= \pi \frac{\int Q_e r^2 n(r) dr}{\int r^2 n(r) dr} \frac{\int r^2 n(r) dr}{\int n(r) dr} \int n(r) dr \Delta h \\
&= Q_e \pi r_{rms}^2 N \Delta h
\end{aligned}$$

$$\begin{aligned}
W &= \rho_w \frac{4}{3} \pi \int r^3 n(r) dr \\
&= \rho_w \frac{4}{3} \pi \frac{\int r^3 n(r) dr}{\int n(r) dr} \int n(r) dr \\
&= \rho_w \frac{4}{3} \pi r_v^3 N \\
r_{eff} &= \frac{r_v^3}{r_{rms}^2}
\end{aligned}$$

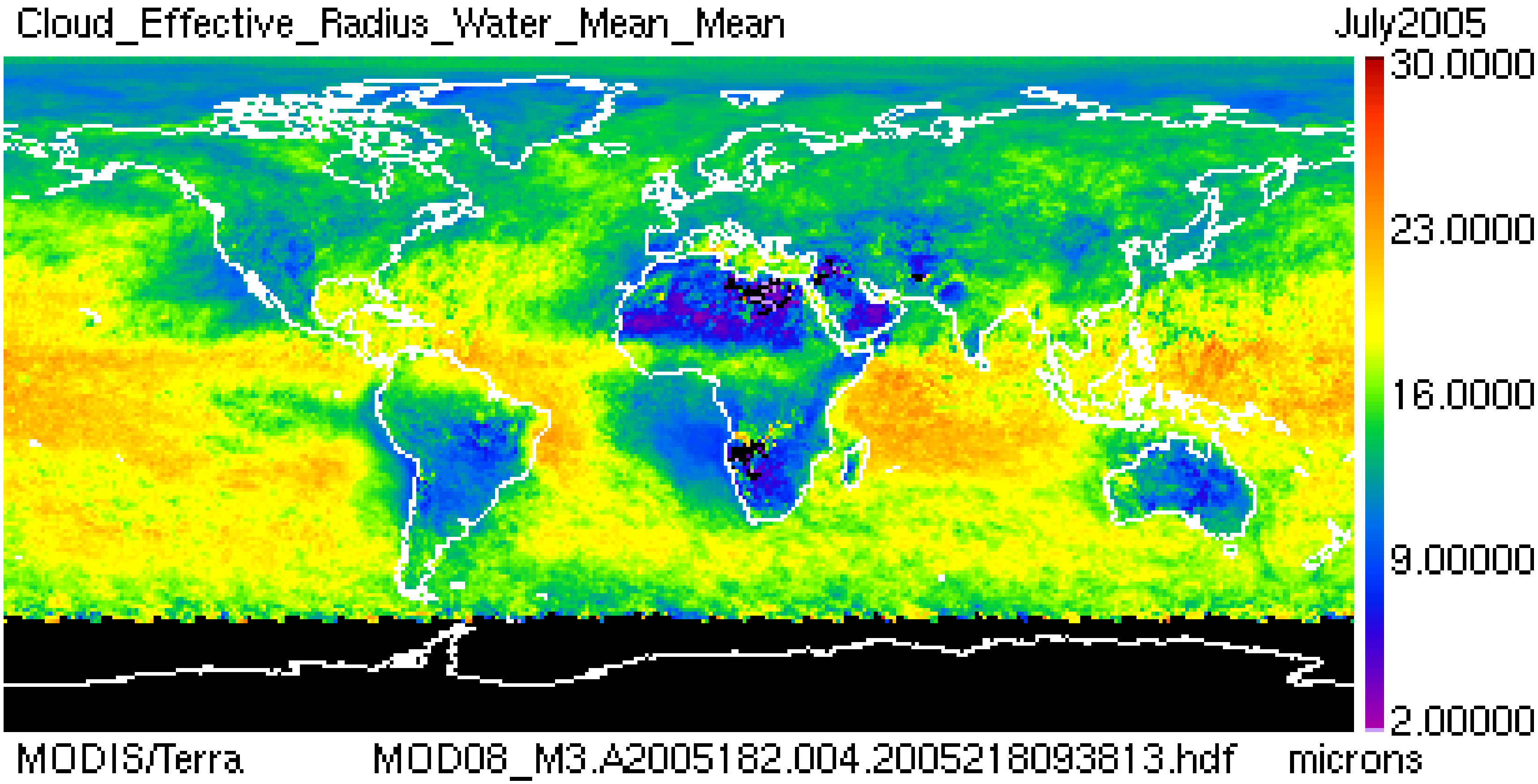
$$\begin{aligned}
\tau &= \frac{3 Q_e W \Delta h}{4 r_{eff} \rho_w} \\
\tau &= \frac{3 W \Delta h}{2 r_{eff}} \\
LWP &= \frac{2}{3} \tau r_{eff}
\end{aligned}$$

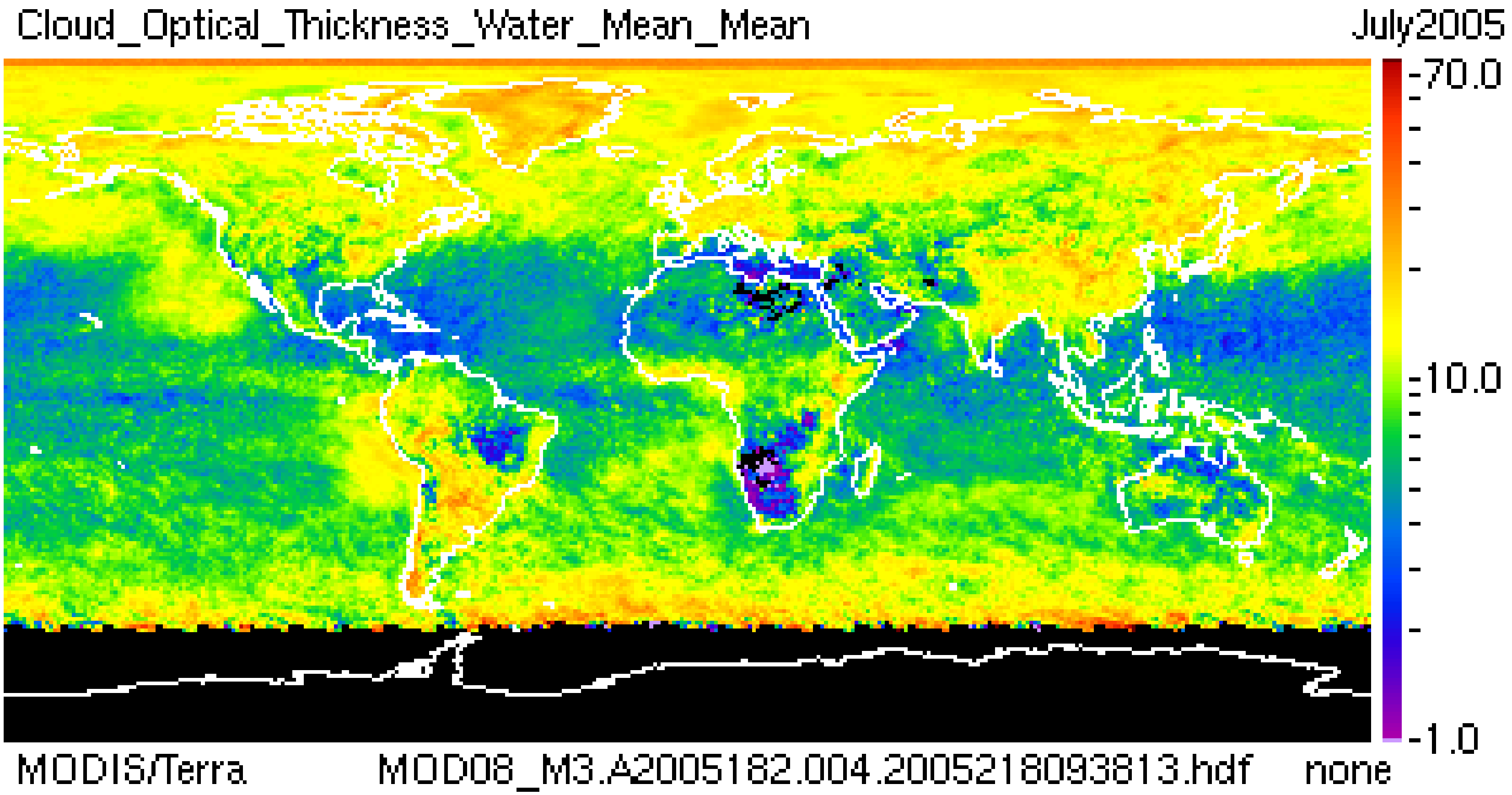
$$r_v = k r_{rms}$$

$$\begin{aligned}
\tau &= Q_e \frac{1}{k^2} \pi \left(\frac{W}{\rho_w (4/3) \pi} \right)^{2/3} N^{1/3} \Delta h \\
\tau &\propto N^{1/3}
\end{aligned}$$

Why is aerosol indirect effect important?

Retrieval

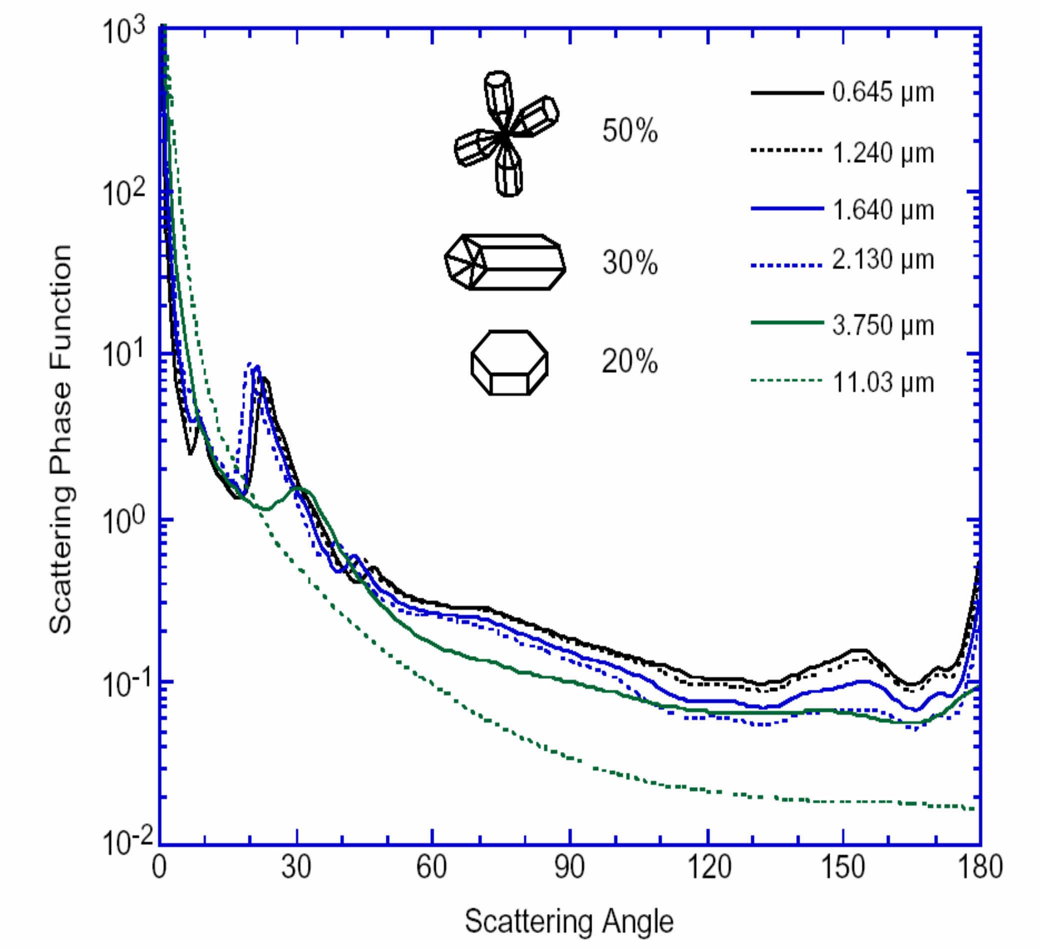

Cloud_Effective_Radius_Water_Mean_Mean
July2005
30.0000
23.0000
16.0000
9.00000
2.00000
MODIS/Terra
MOD08_M3.A2005182.004.2005218093813.hdf
microns


Cloud_Optical_Thickness_Water_Mean_Mean
July2005
70.0
10.0
1.0
MODIS/Terra
MOD08_M3.A2005182.004.2005218093813.hdf
none

Retrieval of Ice cloud

Complicated:

Shape



Cloud retrieval algorithm for MODIS: http://modis.gsfc.nasa.gov/

Other challenge issues

- Cloud phase
- Cloud morphology
- Ice crystals