Size distributions from AERONET : Accuracy, Issues, Improvements

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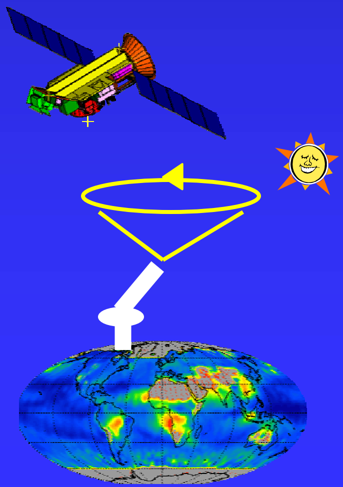


Forward model:

-Spectral and angular scattering by particles with different sizes, compositions and shapes

- Accounting for multiple scattering in atmosphere

(Dubovik and King, JGR, 2000)

Observations

Numerical inversion:

-Accounting for noise

-Solving Ill-posed problem

- Setting a priori constraints

aerosol particle sizes,

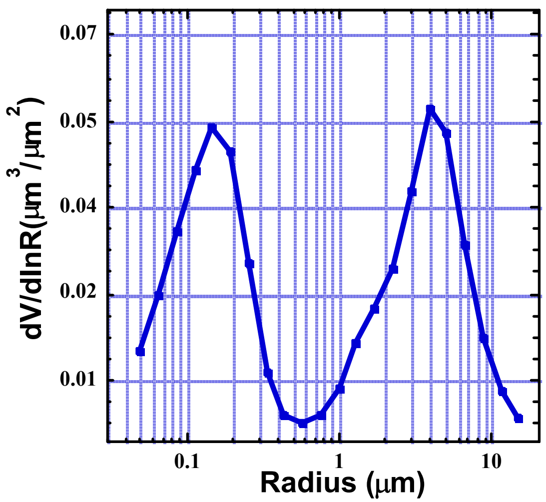
refractive index,

single scattering albedo, etc.

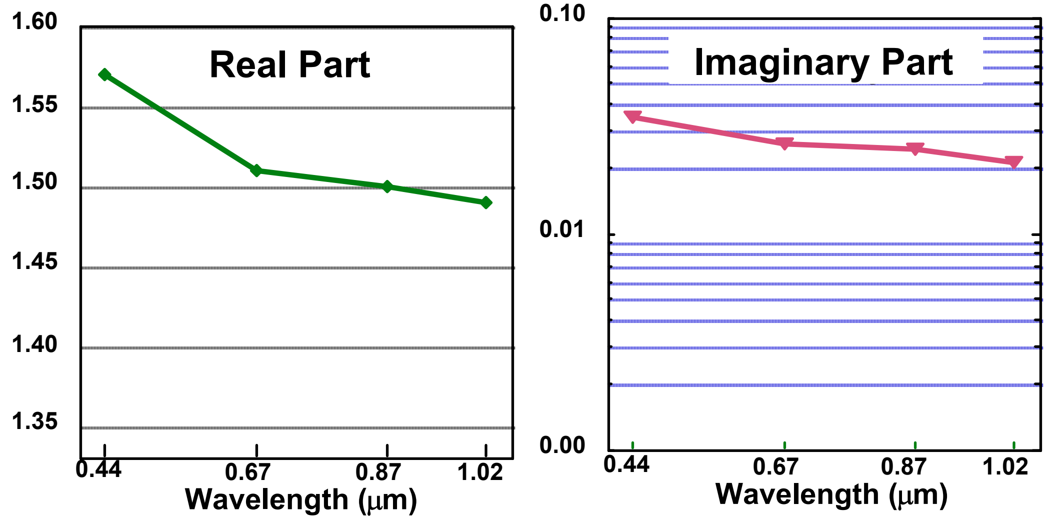
INPUT *of Forward Model*

Single scattering: aerosol particles - homogeneous spheres

Particle Size Distribution:
0.05 μm ≤ R (22 bins) ≤ 15 μm



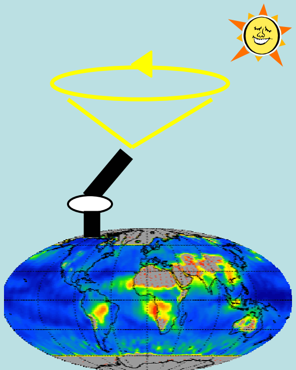
Complex Refractive Index at
λ = 0.44; 0.67; 0.87; 1.02 μm

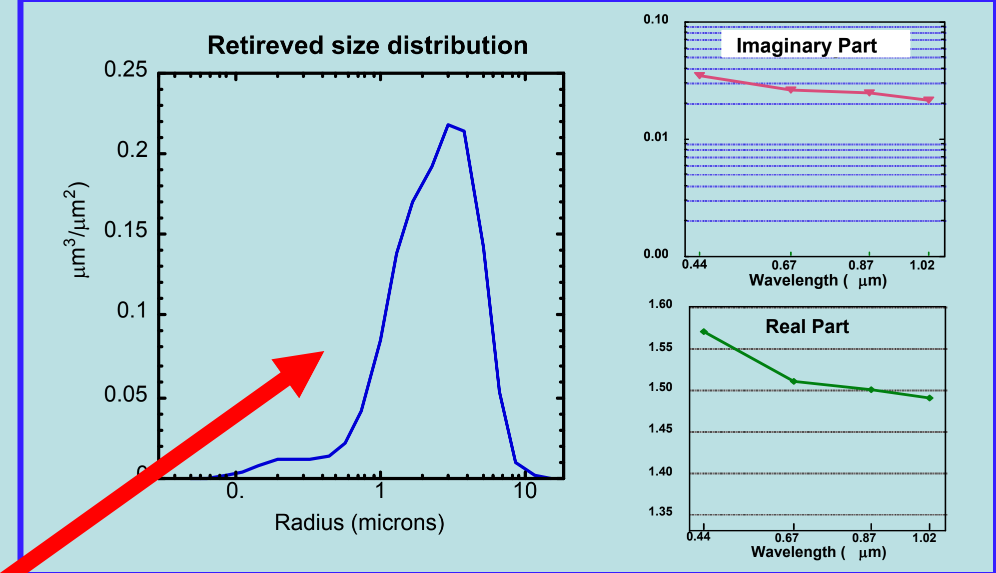


Multiple scattering:

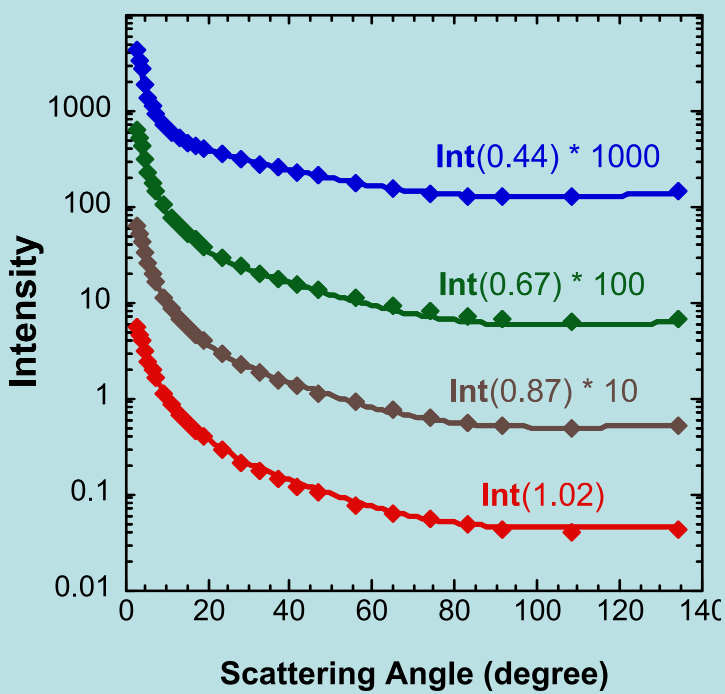
scalar radiative transfer with Lambertian ground reflectance solved by DisOrds (Nakajima-Tanaka or Stamnes et al.)

Fitting as a retrieval strategy

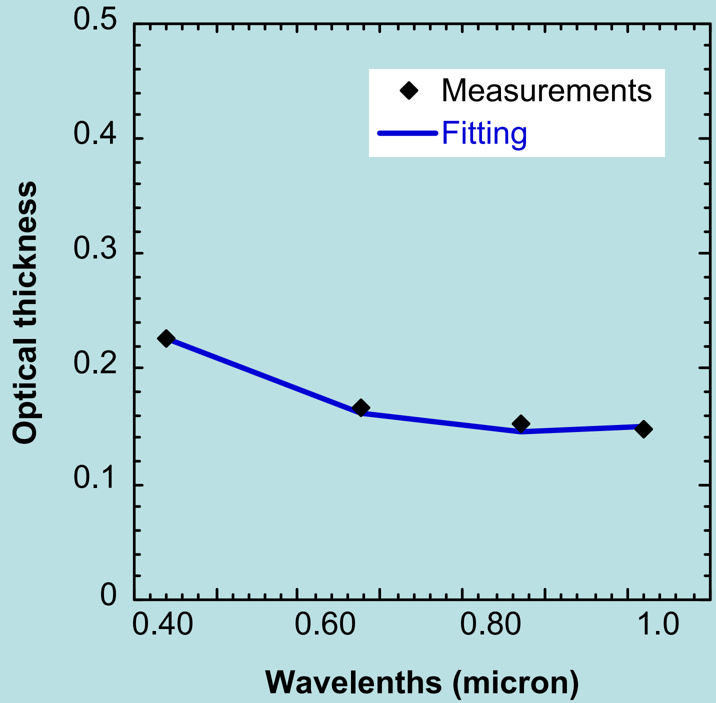




Almucantar Fitting



Fitting of optical thickness in retrievals



Accuracy ???

Theoretical limitations

Forward model:

- particle shapes: spheres, spheroids (shape retrieval ?)
- particles are homogeneous (bi-components ?)
- horizontal homogeneous
- vertically homogenous aerosol or assumed profile of extinction (?)
- assumed surface albedo or assumed BRDF
- assumed gaseous absorption

Inversion assumptions:

- smoothness constraints on size distribution
- smoothness constraints of spectral dependence of ref. Index
- log-normal distribution of random errors

Perspectives:

- assuming bi-component aerosols
- retrieval of BRDF from combination of AERONET with satellite and aircraft observations
- retrieval of shape distribution

Measurement limitations

Geometry:

- scattering angle coverage: ~ 3^0 (1^0 - ?) - 150^0

- spectral coverage: ~ 0.34 - 1.6 μm

Measurement accuracies:

- optical thickness: ~ 0.01-0.02

- sky-channel calibration: ~ 5 %

- azimuth angle pointing: ~ 0.5^0

- degree of linear polarization: ~ 1-2 % (?)

- consistency between polarization and intensity: good (?)

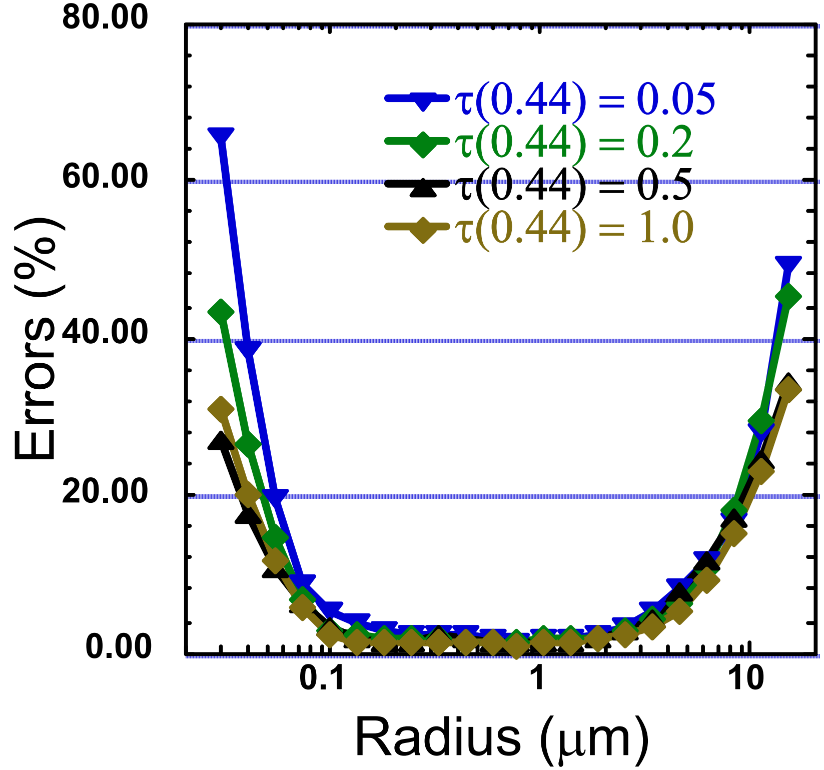
- cloud contamination: almucantar (good), principle plane (???)

Random ERRORS in AERONET retrievals

ASSUMPTIONS:

- measurements have Normal Noise:
  - **optical thickness:** $\sigma = 0.01$
  - **sky-radiances:** $\sigma = 5\%$

CONCLUSIONS:
- the retrievals stable
- important tendencies outlined



Sensitivity to instrumental offsets

Offsets were considered in:

- **optical thickness:** $\Delta\tau(\lambda) = \pm 0.01;\ \pm 0.02;$
- **sky-channel calibration:** $\Delta_I(\lambda;\Theta)/I(\lambda;\Theta)\ 100\% = \pm 5\%;$
- **azimuth angle pointing:** $\Delta\phi = 0.5^o;\ 1^o;$
- **assumed ground reflectance:** $\Delta A(\lambda)/A(\lambda)\ 100\% = \pm 30\%;\ \pm 50\%;$

Aerosol models considered (bi - modal log-normal):

- **Water-soluble aerosol for $0.05 \le \tau(440) \le 1$;**
- **Desert dust for $0.5 \le \tau(440) \le 1$;**
- **Biomass burning for $0.5 \le \tau(440) \le 1$;**

Results summary:

- $\tau(440) \le 0.2$ - $dV/d\ln r$ (+), $n(\lambda)$ (-), $k(\lambda)$ (-), $\omega_0(\lambda)$ (-)
- $\tau(440) > 0.2$ - $dV/d\ln r$ (+), $n(\lambda)$ (+), $k(\lambda)$ (+), $\omega_0(\lambda)$ (+)
- **Angular pointing accuracy is critical for $dV/d\ln r$ of dust**

(+) **CAN BE** retrieved (-) **CAN NOT BE** retrieved

Sensitivity to forward model limitations

Mixed aerosols (inhomogeneous spherical aerosols):

- Externally mixed (n(l) and k(l) different for fine and coarse modes)
- Internally mixed (n(l) and k(l) different for core and shell) - *Biomass Burning*

Results summary:

- $dV/d\ln r$ (+), $\omega_0(\lambda)$ (+), $n(\lambda)$ (+,*effective*), $k(\lambda)$ (+, *effective*)

Non-spherical aerosols:

- Spheroids (prolate, axis ratio 2) - *Desert dust*

Results summary:

- $dV/d\ln r$ - coarse mode (+), fine mode (+, zenith angle < 25°)
- $\omega_0(\lambda)$ (+) - full solar almucantar (zenith angle ≥ 50°)
- $k(\lambda)$ (+)
- $n(440)$ (-), $n(670)$ (-), $n(870)$ (+/-), $n(1020)$ (+)

(+) CAN BE retrieved (-) CAN NOT BE retrieved

Retrieval accuracy and limitations

Sensitivity tests by Dubovik et al. 2000

Effective

wide angular coverage

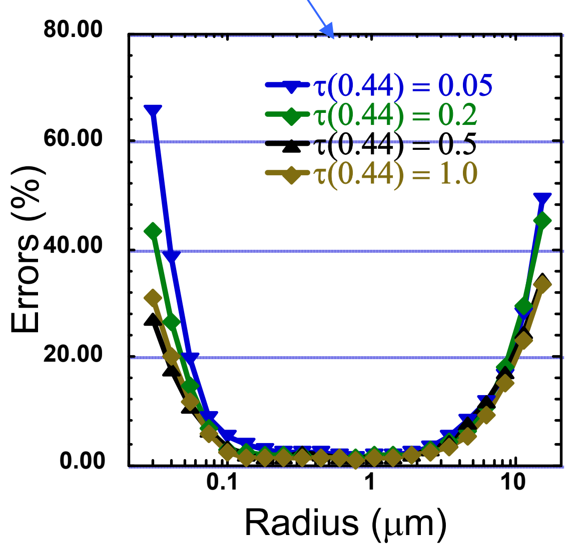
bias $\Delta\tau = \pm 0.01$

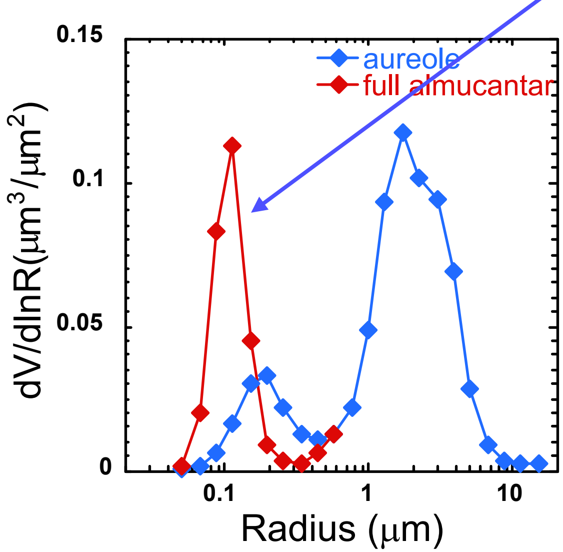
	$\tau(0.44) \leq 0.2$	$\tau(0.44) \geq 0.5$
Real Part	0.05	0.025
Imaginary Part	80-100%	50%
SSA	0.05-0.07	**0.03**

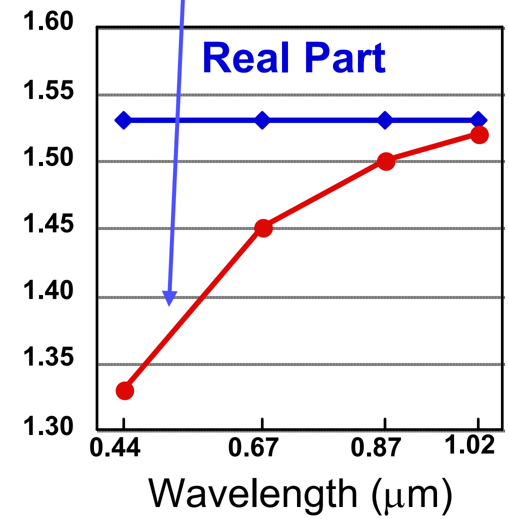
Random errors

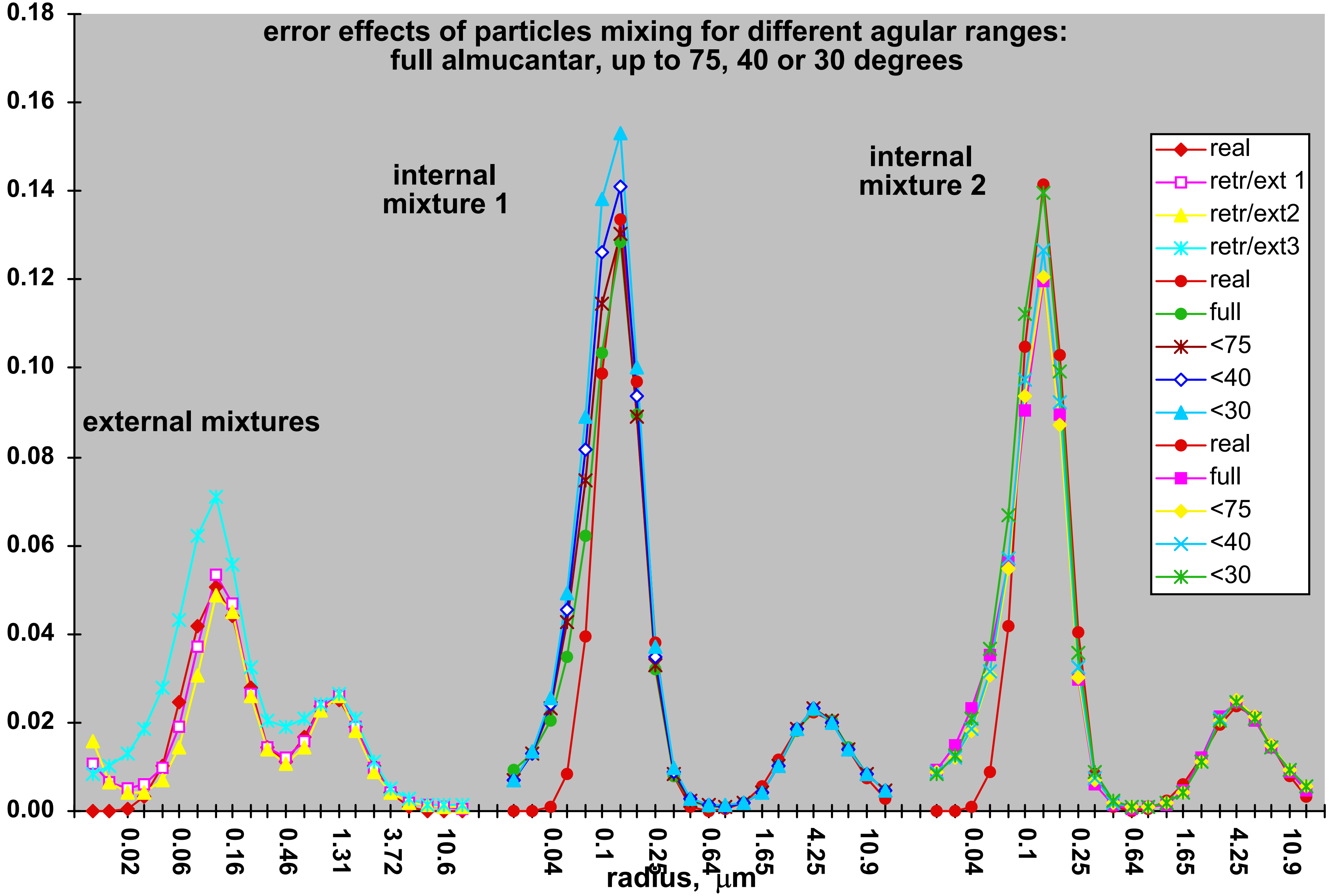
Size Distribution:

Nonsphericity biases









error effects of particles mixing for different agular ranges:
full almucantar, up to 75, 40 or 30 degrees
external mixtures
internal mixture 1
internal mixture 2
real
retr/ext 1
retr/ext2
retr/ext3
real
full
<75
<40
<30
real
full
<75
<40
<30
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.02
0.06
0.16
0.46
1.31
3.72
10.6
0.04
0.1
0.25
0.64
1.65
4.25
10.9
0.04
0.1
0.25
0.64
1.65
4.25
10.9
radius, μm

AERONET inversion scenarios

Almucantar:

$\tau(\lambda)$, $I(\lambda,\Theta)$

λ= 0.38, 0.44, 0.5, 0.67, 0.87, 1.02, 1.64, μm

Principal Plane:

$\tau(\lambda)$, $I(\lambda,\Theta)$

λ = 0.38, 0.44, 0.5, 0.67, 0.87, 1.02, 1.64, μm

Polarized Principal Plane:

$\tau(\lambda)$, $I(\lambda,\Theta)$,$P(\lambda,\Theta)$

λ = 0.87μm

satellite, aircraft, etc.

spheres

spheroids

Inversion Products:

$dV/d\ln(r_i)$

$n(\lambda)$

$k(\lambda)$

BRDF

errors

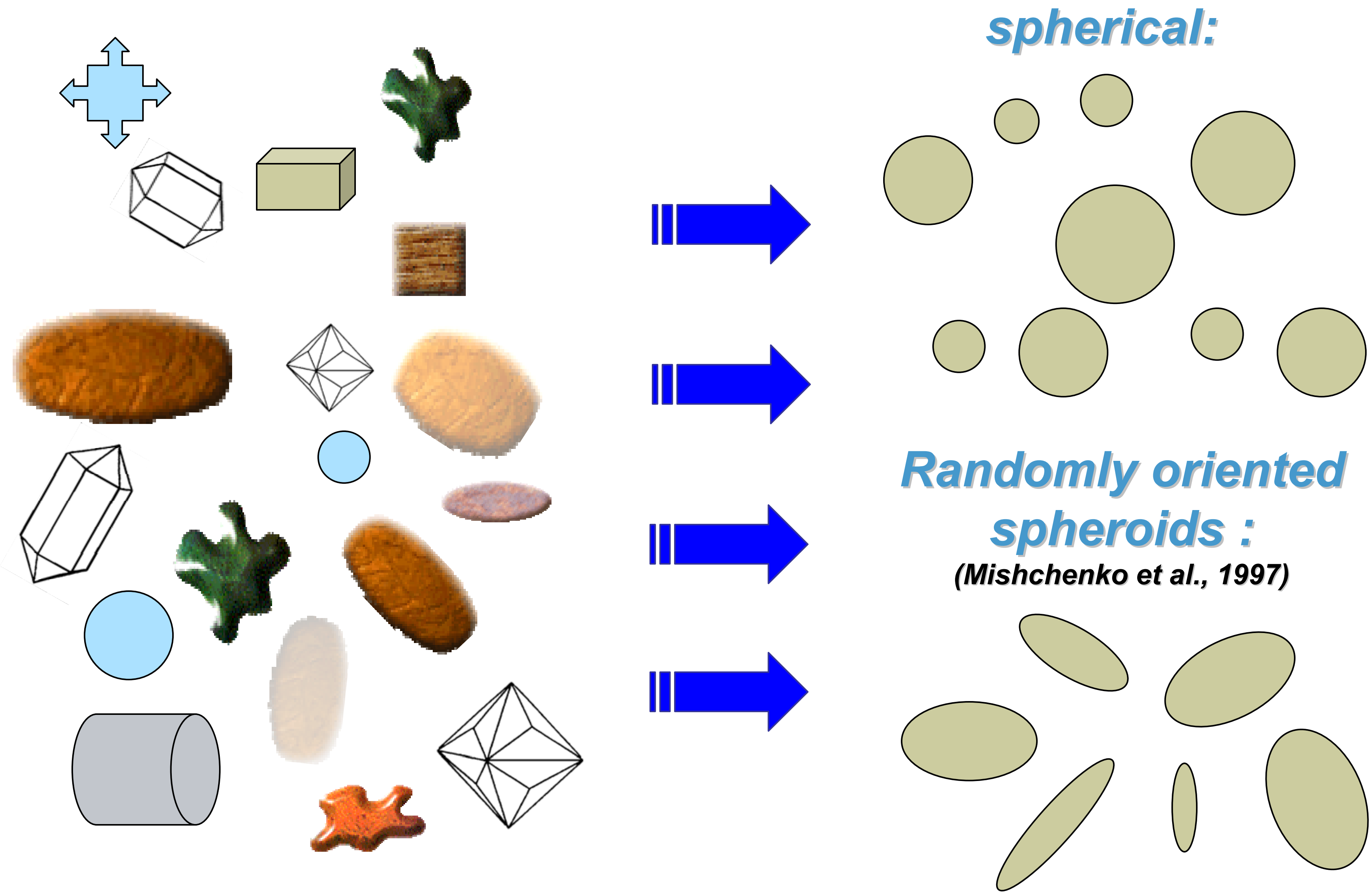
$\omega_0(\lambda)$

$P_{11}(\lambda)$, $P_{12}(\lambda)$, ...

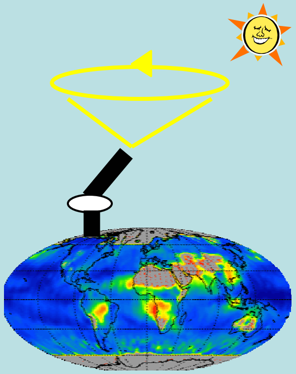
fine & coarse

fluxes, …

AERONET model of aerosol



spheroid kernels data base for operational modeling !!!

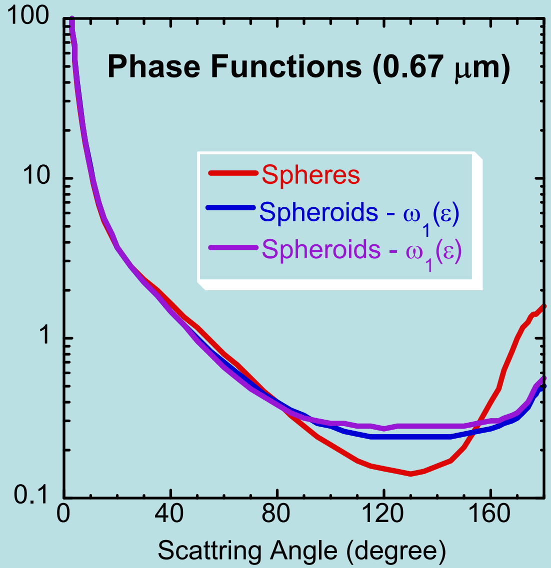


K - pre-computed kernel matrices:
Input: n and k

Input: ω_p (N_p =11),
$V(r_i)$ (N_i =22 -26)

Basic Model by Mishchenko et al. 1997:
- randomly oriented homogeneous spheroids
- *ω(ε)* - size independent shape distribution

$$\tau(\lambda),\mathbf{F}_{11},...,\mathbf{F}_{44} \approx \sum_{(i;p)} \mathbf{K}_{ip}(...;n;k)\,\omega_p\,V(r_i)$$

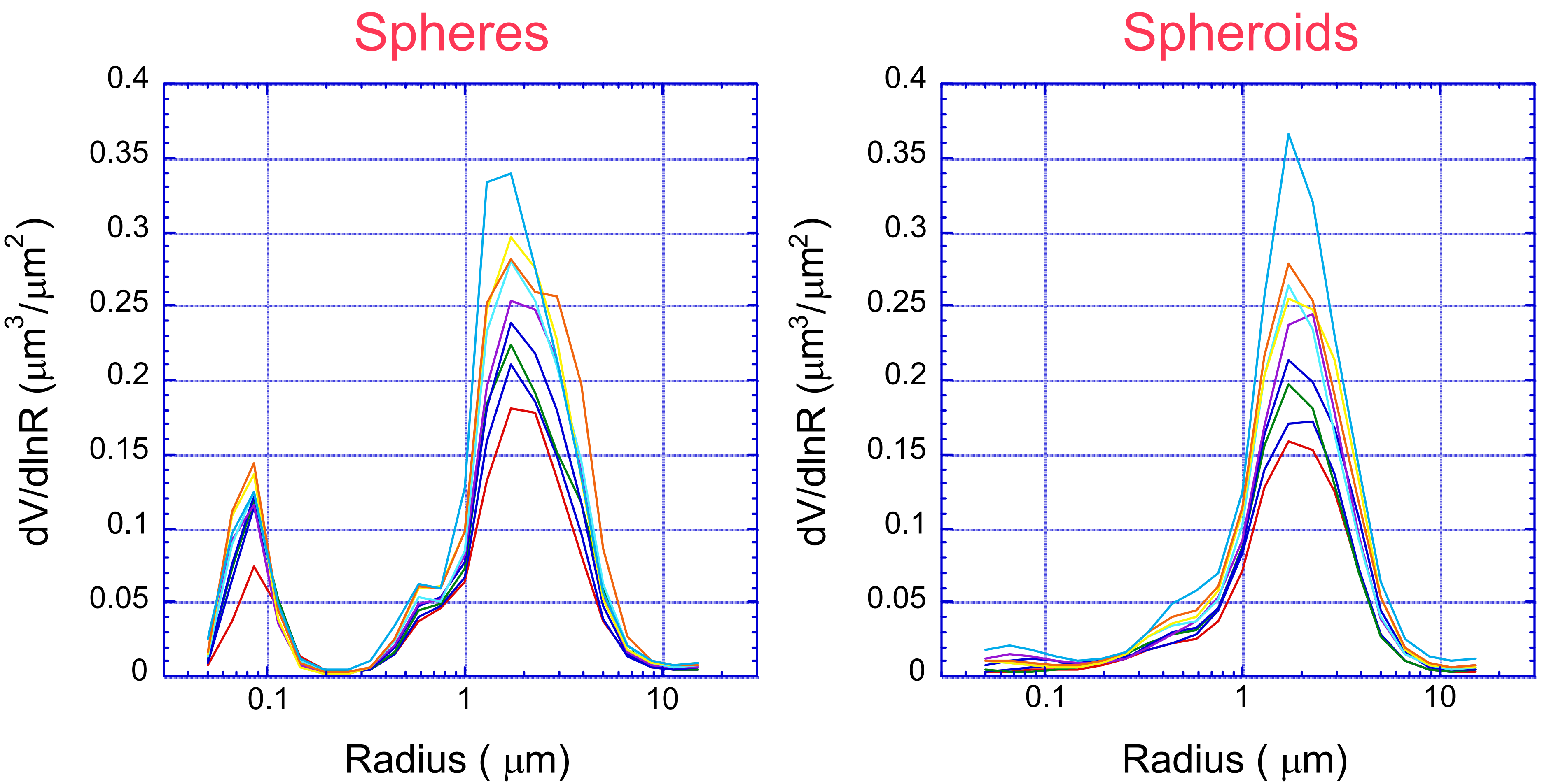


Time: < one sec.
Accuracy: < 1-3 %
Range of applicability:
$0.15 \le 2\pi r/\lambda \le 280$ (26 bins)
$0.4 \le \varepsilon \le 2.4$ (11 bins)
$1.33 \le n \le 1.6$
$0.0005 \le k \le 0.5$

Output: $\tau(\lambda)$, $\omega_0(\lambda)$, $F_{11}(\Theta)$, $F_{12}(\Theta)$, $F_{22}(\Theta)$, $F_{33}(\Theta)$, $F_{34}(\Theta)$, $F_{44}(\Theta)$

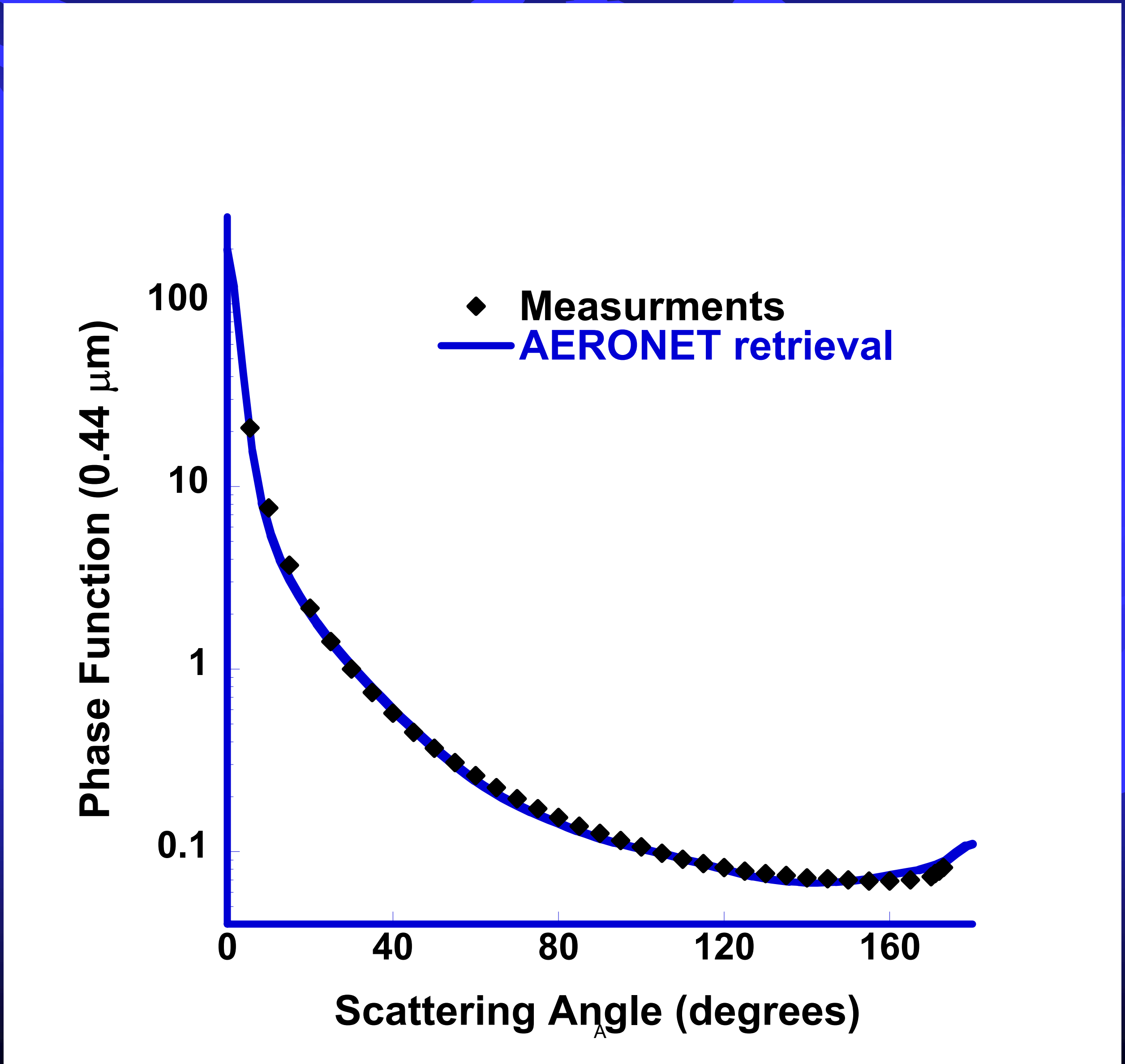
Cape Verde (2001) dust Size distributions

(110 cases; $\tau(1020) \geq 0.3$; $\alpha \leq 0.6$)

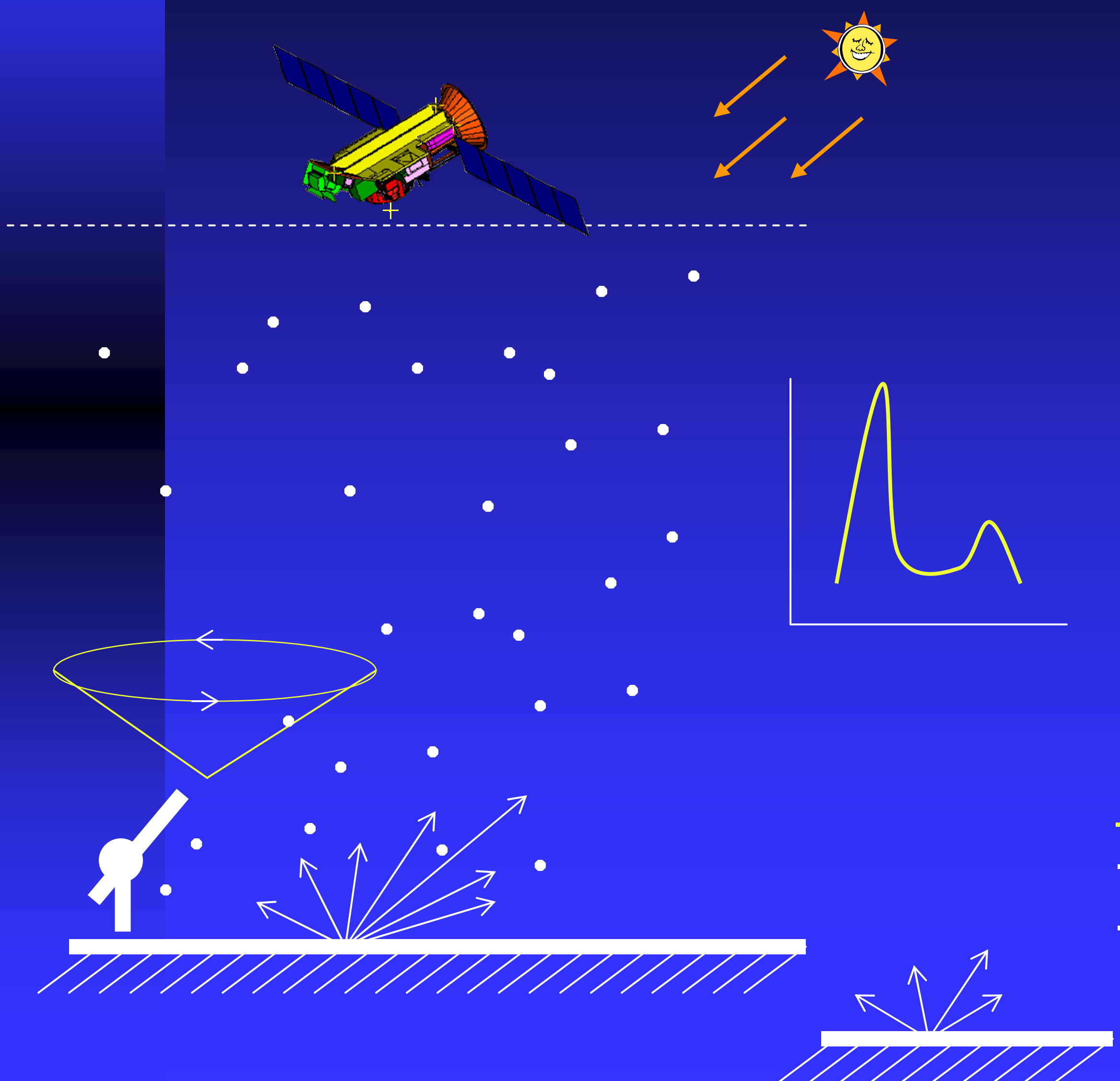


9 groups: τ = 0.39, 0.44, 0.48, 0.50, 0.52, 0.57, 0.60, 0.62,0.71

Comparison of “laboratory” Phase Function with typical AERONET retrieval



Retrieval using combinations of up-looking Ground-based and down-looking satellite observations



Retrieved:

Aerosol Properties:
- *size distribution*
- *real ref. ind.*
- *imag. ref. ind*

(AERONET sky channels)

Surface Parameters:

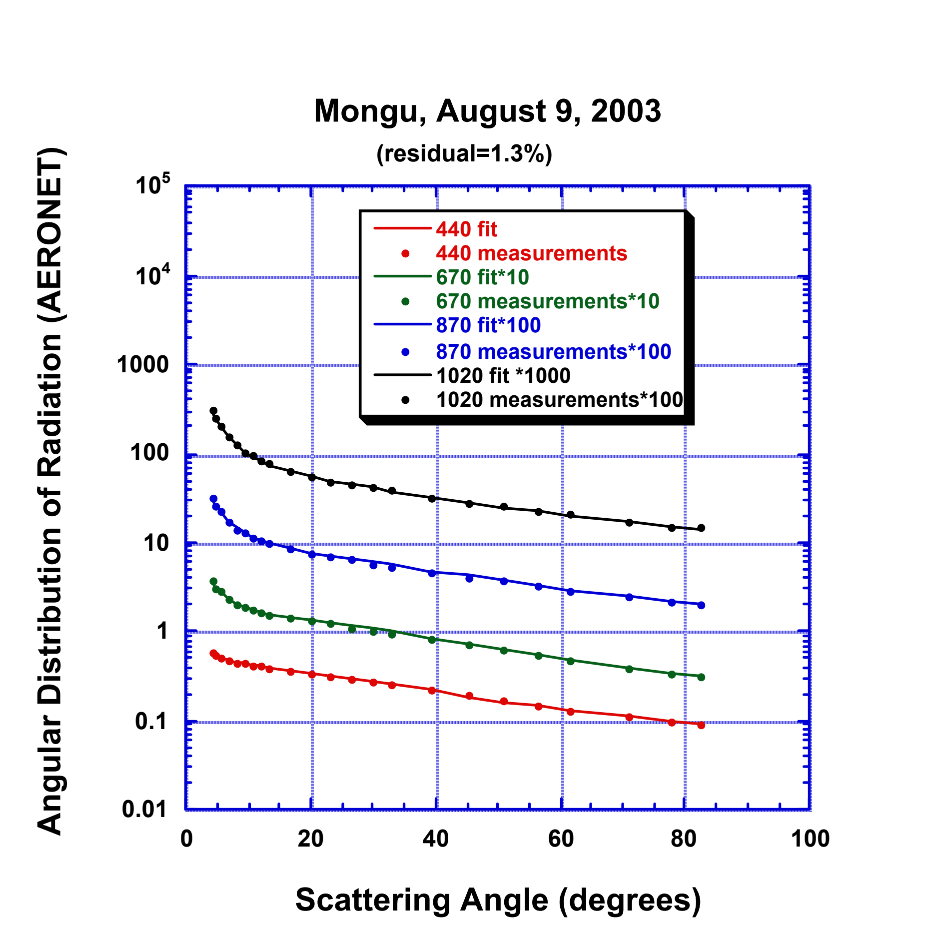
-BRDF (MISR channels)

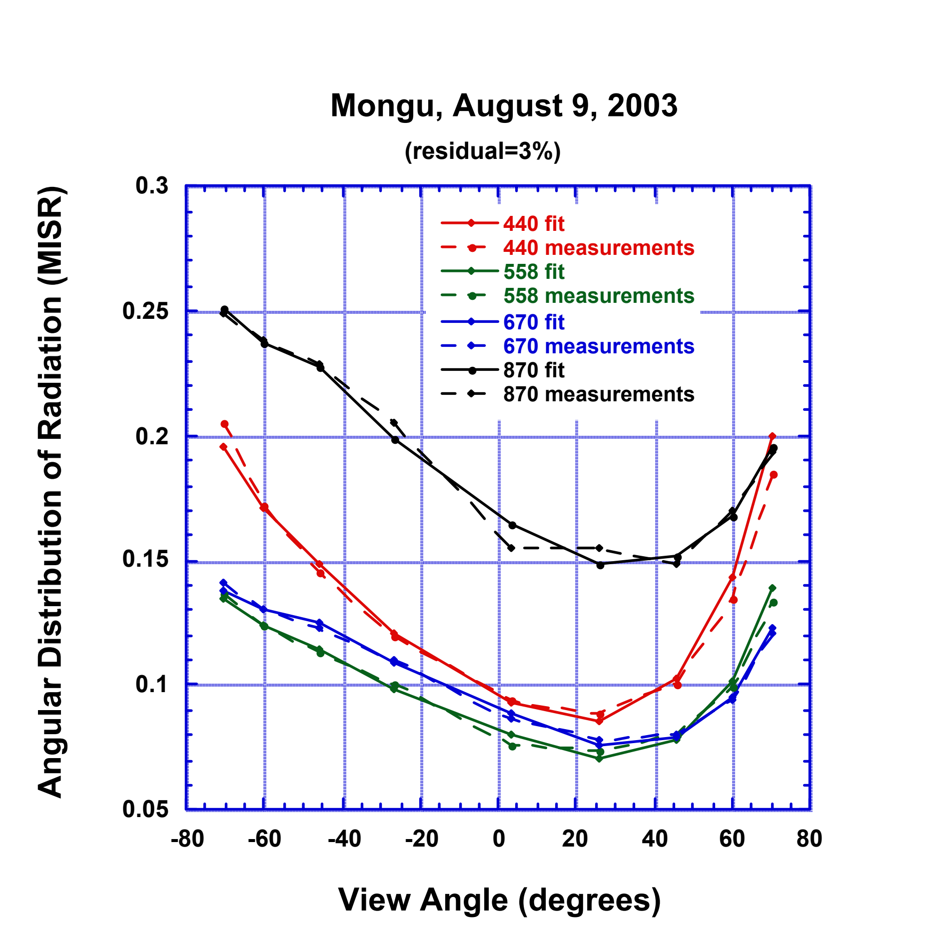
-Albedo (MODIS IR channels)

AERONET-MISR

August 9, 2003
$\tau(0.44) \sim 0.3$

Simultaneous fitting

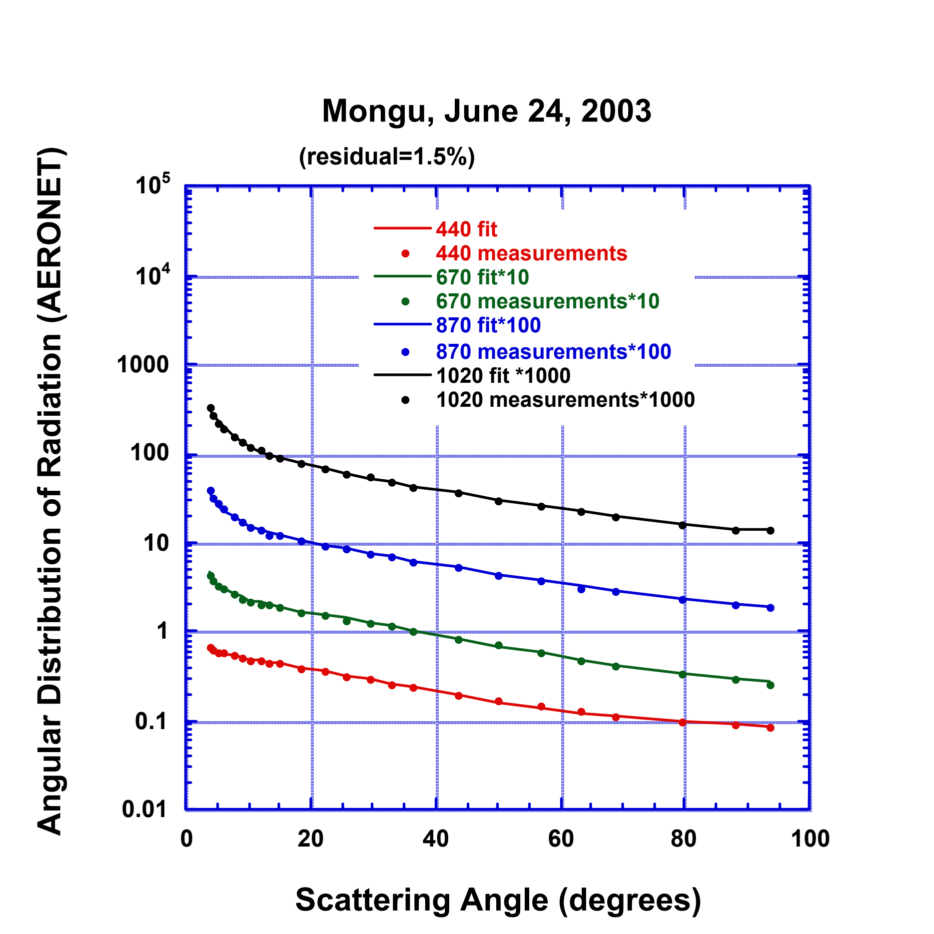


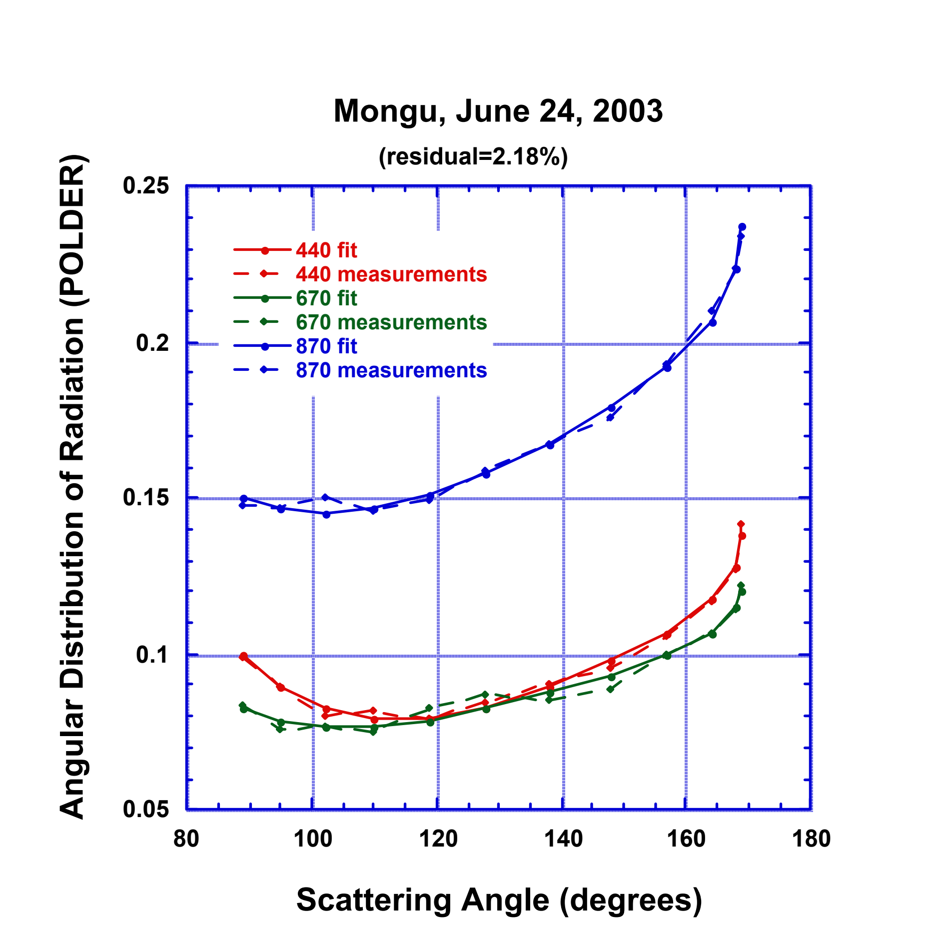


AERONET- POLDER

June 24, 2003
$\tau(0.44) \sim 0.26$

Simultaneous fitting

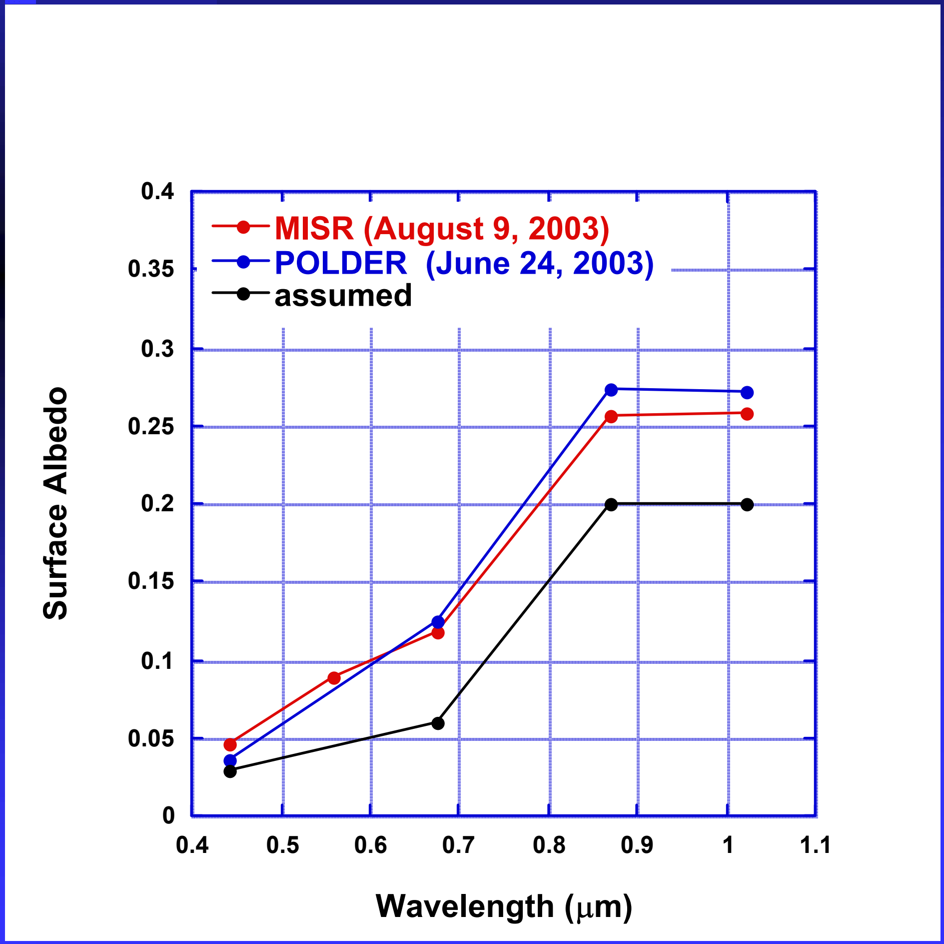


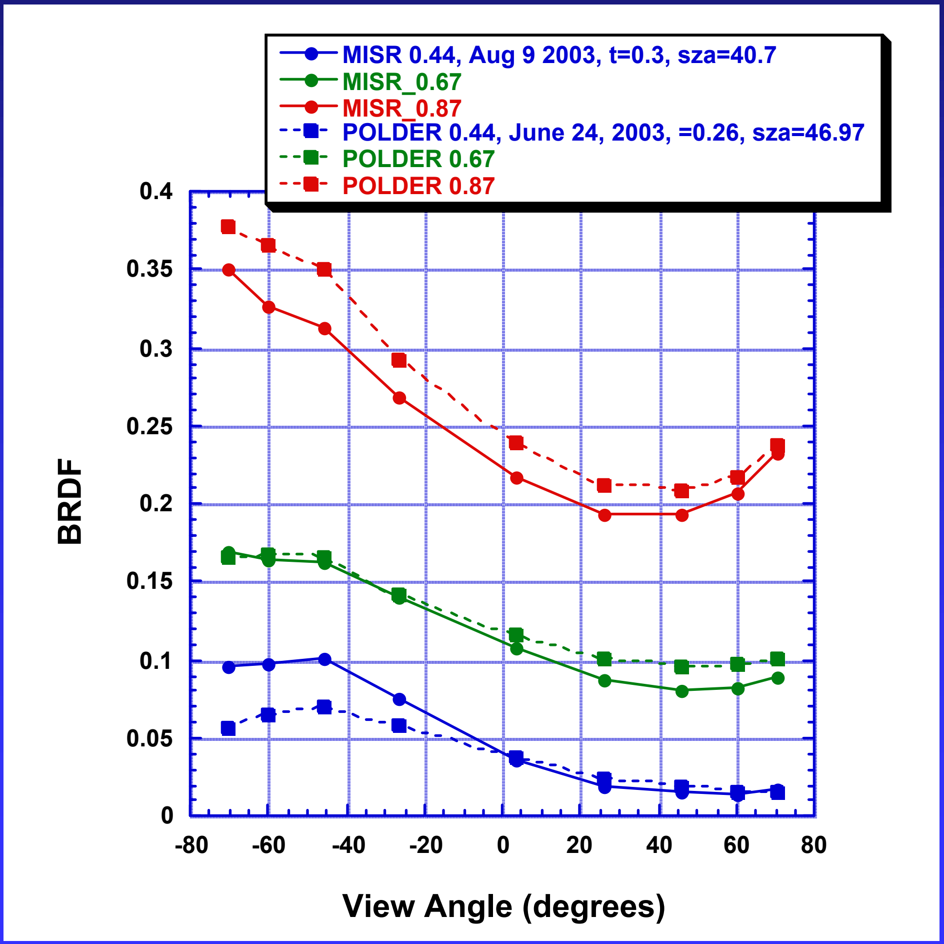


Comparisons of Surface Retrievals

POLDER: June 24, 2003
$\tau(0.44) \sim 0.26$, SZA=47^0

MISR: August 9, 2003
$\tau(0.44) \sim 0.3$, SZA=40^0

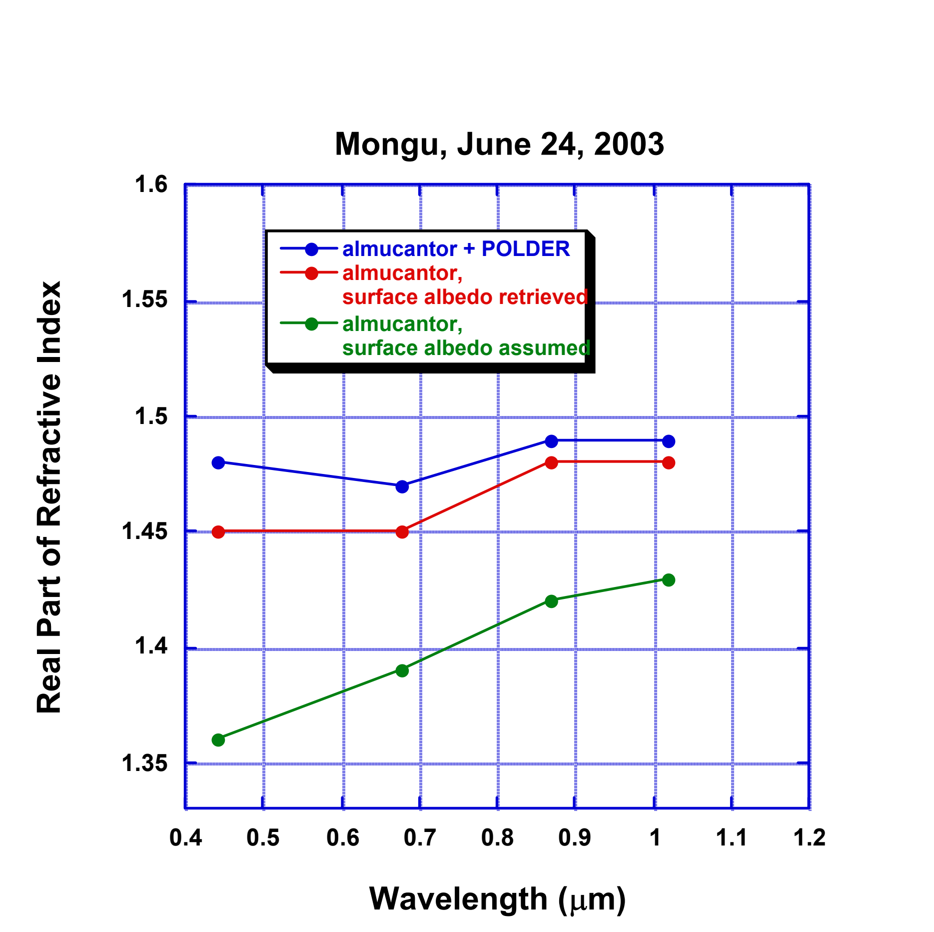


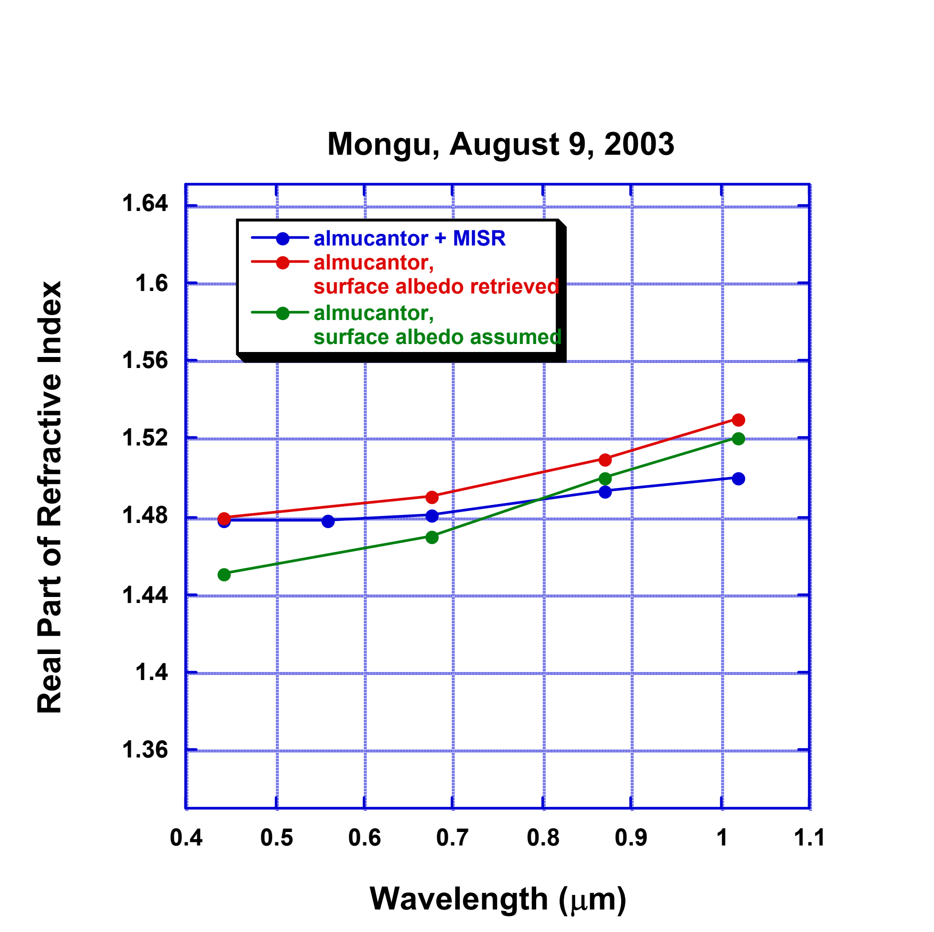


Surface Effect on Retrievals of the Refractive Index (low aerosol loading)

POLDER: June 24, 2003
$\tau(0.44) \sim 0.26$, SZA=47^0

MISR: August 9, 2003
$\tau(0.44) \sim 0.3$, SZA=40^0

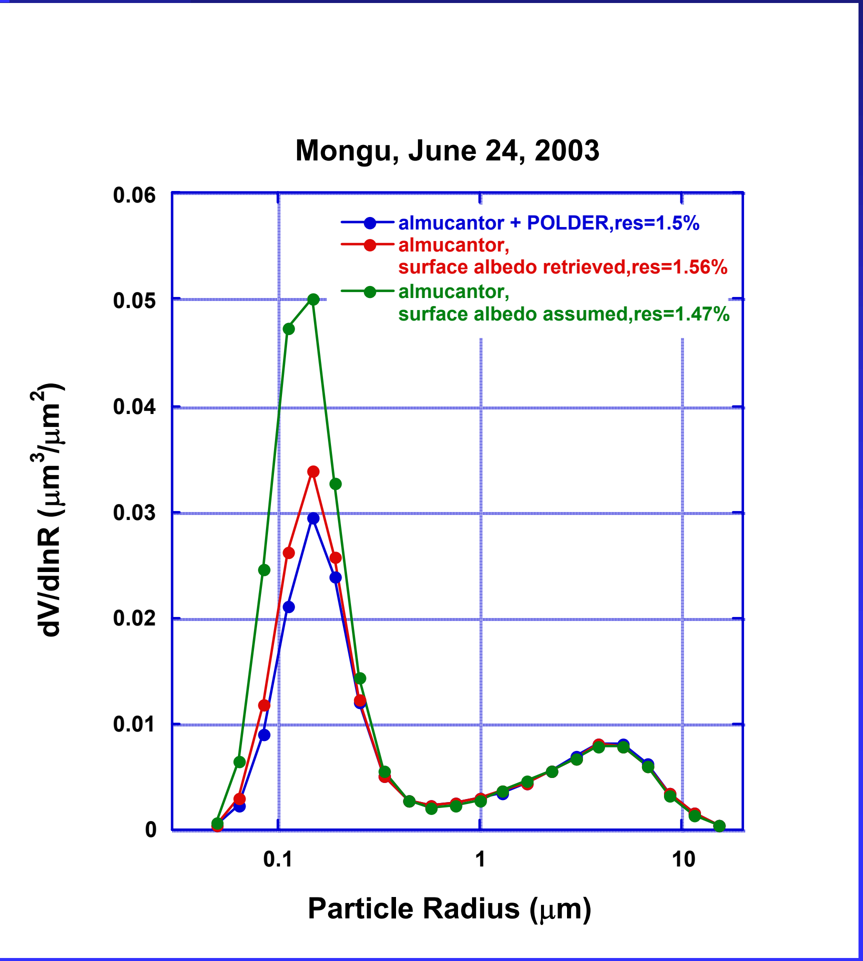


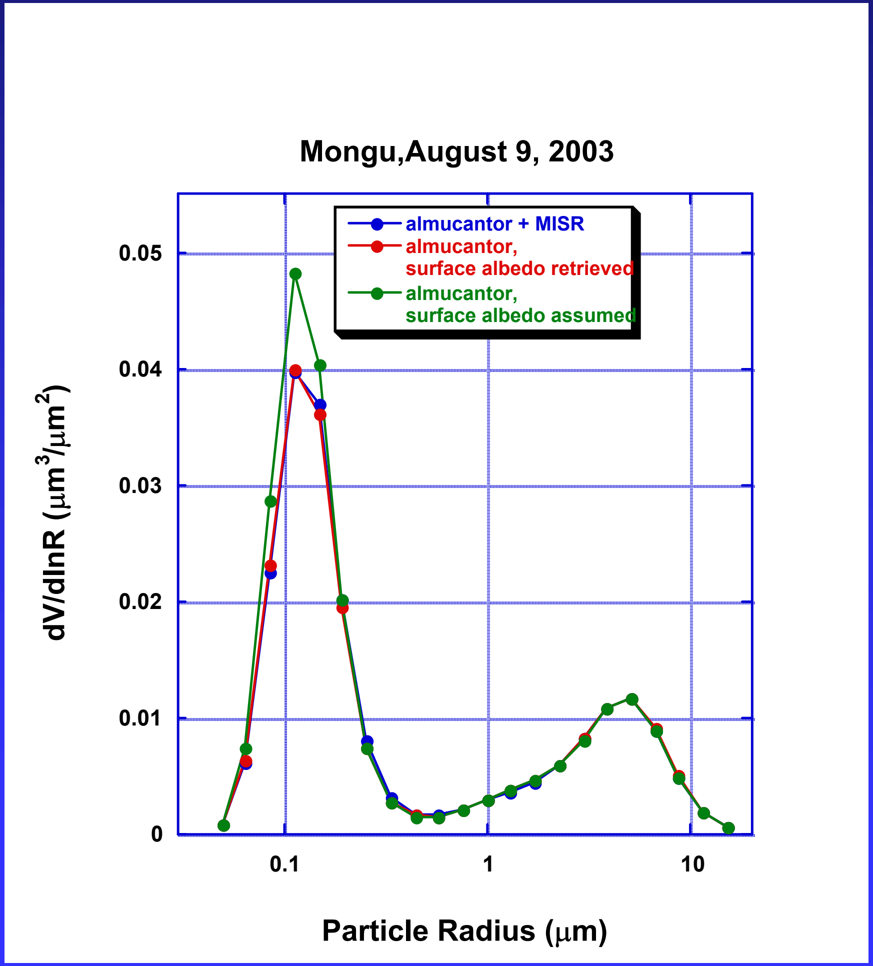


Surface Effect on the Retrievals of the Size Distribution (low aerosol loading)

POLDER: June 24, 2003
$\tau(0.44) \sim 0.26$, $SZA=47^0$

MISR: August 9, 2003
$\tau(0.44) \sim 0.3$, $SZA=40^0$



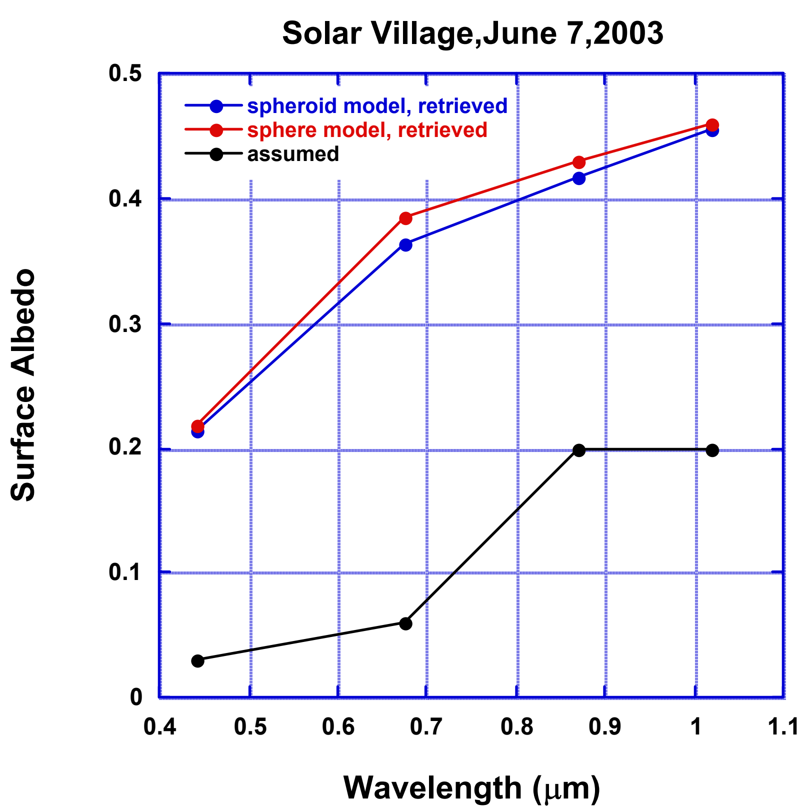


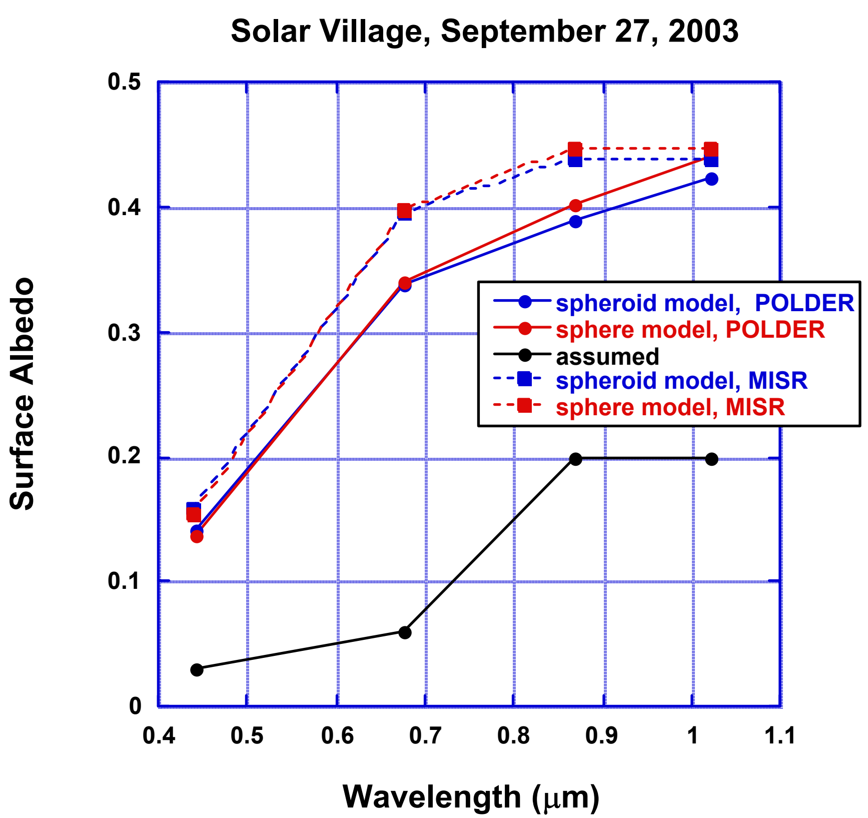
Comparisons of Surface Retrievals (Albedo)

MISR: September 27, 2003
$\tau(0.44) \sim 0.24$, SZA=31^0

POLDER: June 7, 2003
$\tau(0.44) \sim 0.67$, SZA=23^0

POLDER: September 27, 2003
$\tau(0.44) \sim 0.24$, SZA=34^0



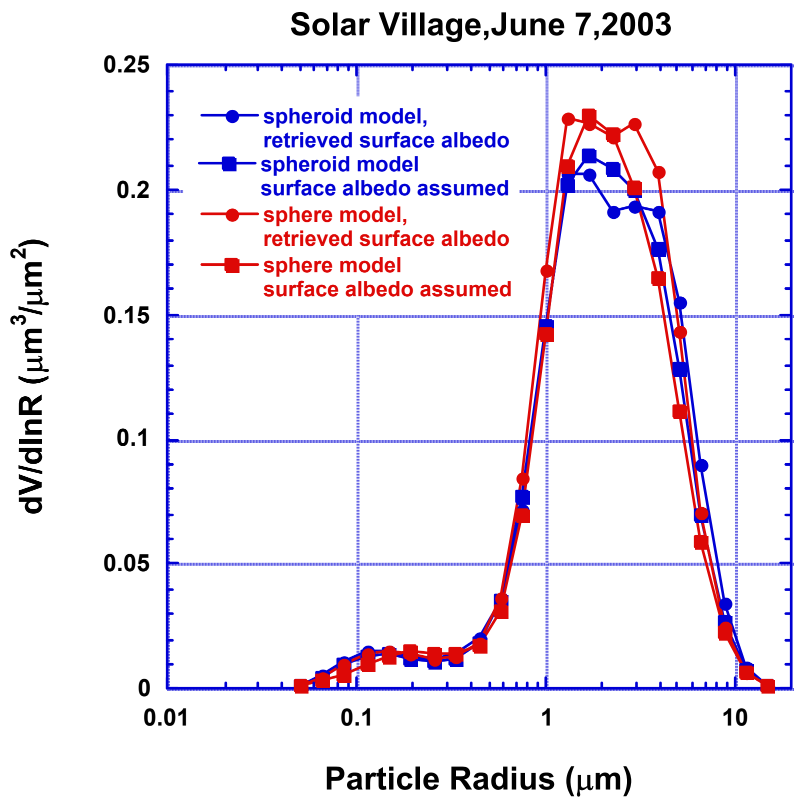


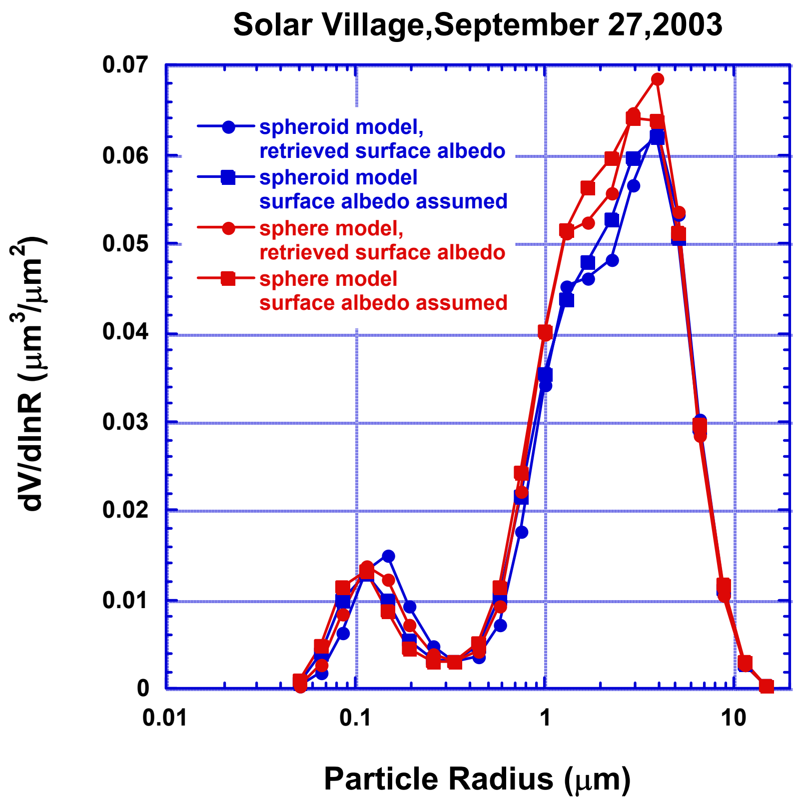
Surface Effect on the Retrievals of Size Distribution

(Principle Plane with corrected surface)

POLDER: June 7, 2003
$\tau(0.44) \sim 0.67$, SZA=70^0

POLDER: September 27, 2003
$\tau(0.44) \sim 0.24$, SZA=70^0





Fitting Accuracy of Radiances
Spheroids and Spheres (principle plane)

Satellite: ~ 1-3%

POLDER: September 27, 2003
$\tau(0.44) \sim 0.24$, SZA=34^0

2.8%

5.5%