Aerosol Optics, Radiative Forcing, and Climate Change

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What Determines the Temperature of the Earth?

Energy Balance: $E_{in}=E_{out}$

$$E_{in} = \pi r^2 (1-\alpha) S \qquad E_{out} = 4\pi r^2 \varepsilon \sigma T^4 \qquad \frac{(1-\alpha)S}{4} = \varepsilon\sigma T^4$$

$$T = \sqrt[4]{\frac{(1-\alpha)S}{4\varepsilon\sigma}} = 289\,K$$

σ **is the Štefan-Boltzmann constant**
S **is the solar irradiance (≈ 1366 W/m²)**
α **is the planetary albedo (≈ 0.29 due to aerosols, clouds, surface)**
ε **is the emissivity (≈ 0.61 due to greenhouse gases, clouds, surface)**

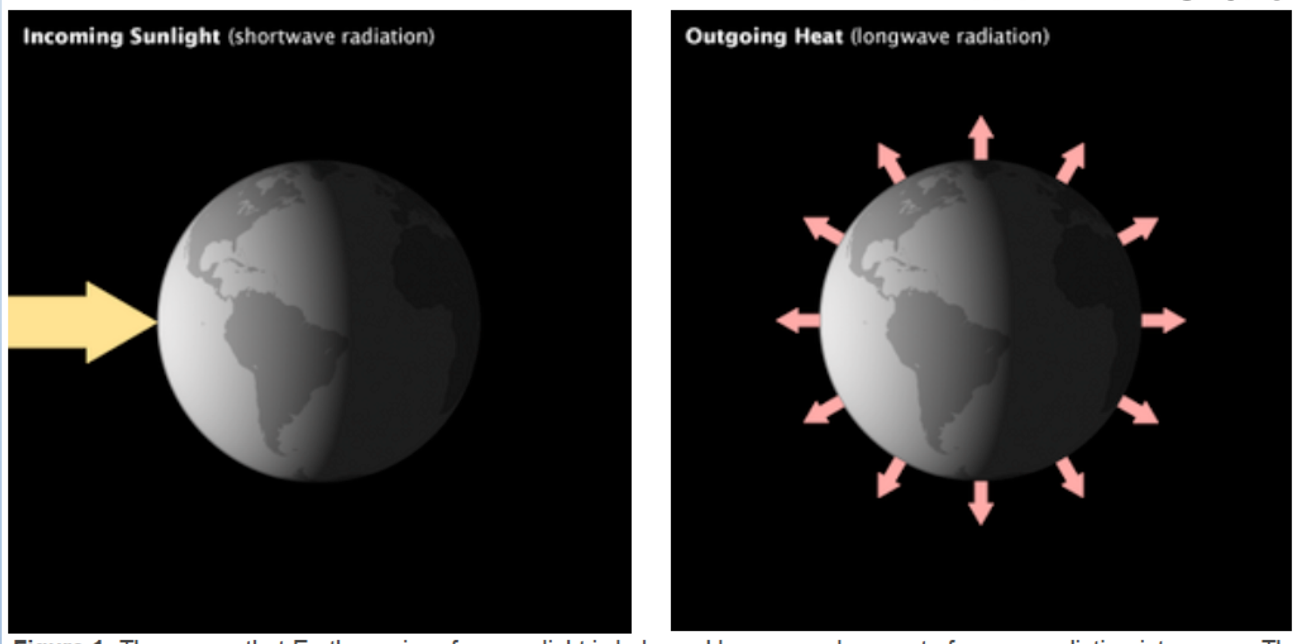
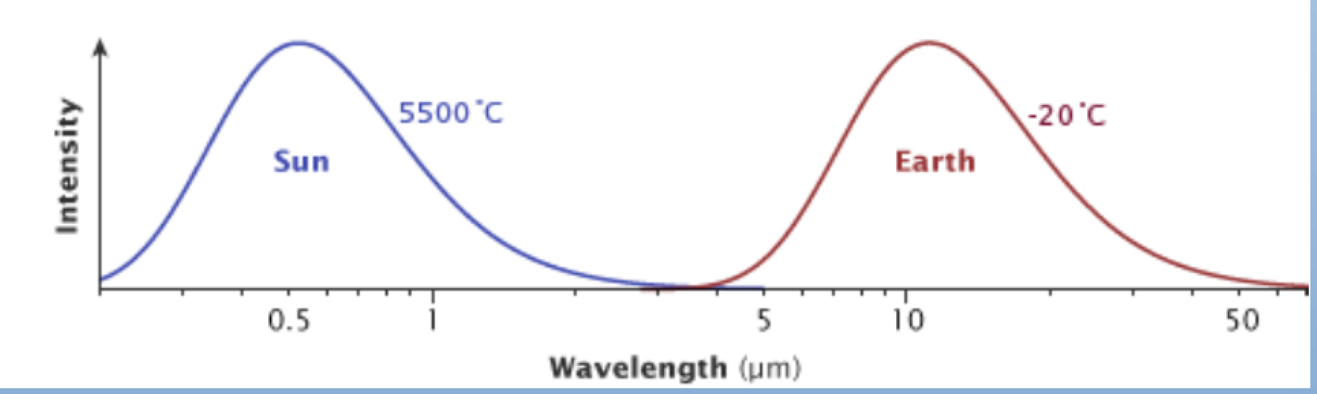


Figure 1. The energy that Earth receives from sunlight is balanced by an equal amount of energy radiating into space. The energy escapes in the form of thermal infrared radiation: like the energy you feel radiating from a heat lamp. (NASA illustrations by Robert Simmon.)



Aerosol Radiative Forcing Efficiency $\Delta F_{aer}/\tau$

$$\frac{\Delta F_{aer}}{\tau} = -\frac{S_0}{2} T_{atm}^2 (1 - A_{cld}) \left[\bar{\beta}\,\omega(1-R_{surf})^2 - 2(1-\omega)R_{surf}\right]$$

Aerosol Extensive Properties

ΔF_{aer} is the aerosol forcing
τ is the aerosol layer optical depth (AOD)
$\Delta F_{aer}/\tau$ is the aerosol forcing efficiency

Aerosol Intensive Properties

$\bar{\beta}$ is the average upscatter fraction
ω is the aerosol single scattering albedo (SSA)

Surface Properties

R_{surf} is the surface albedo

Atmospheric Properties

T_{atm} is the transmittance of the atmosphere above
A_{cld} is the cloud fraction

Solar Properties

S_0 is the solar constant

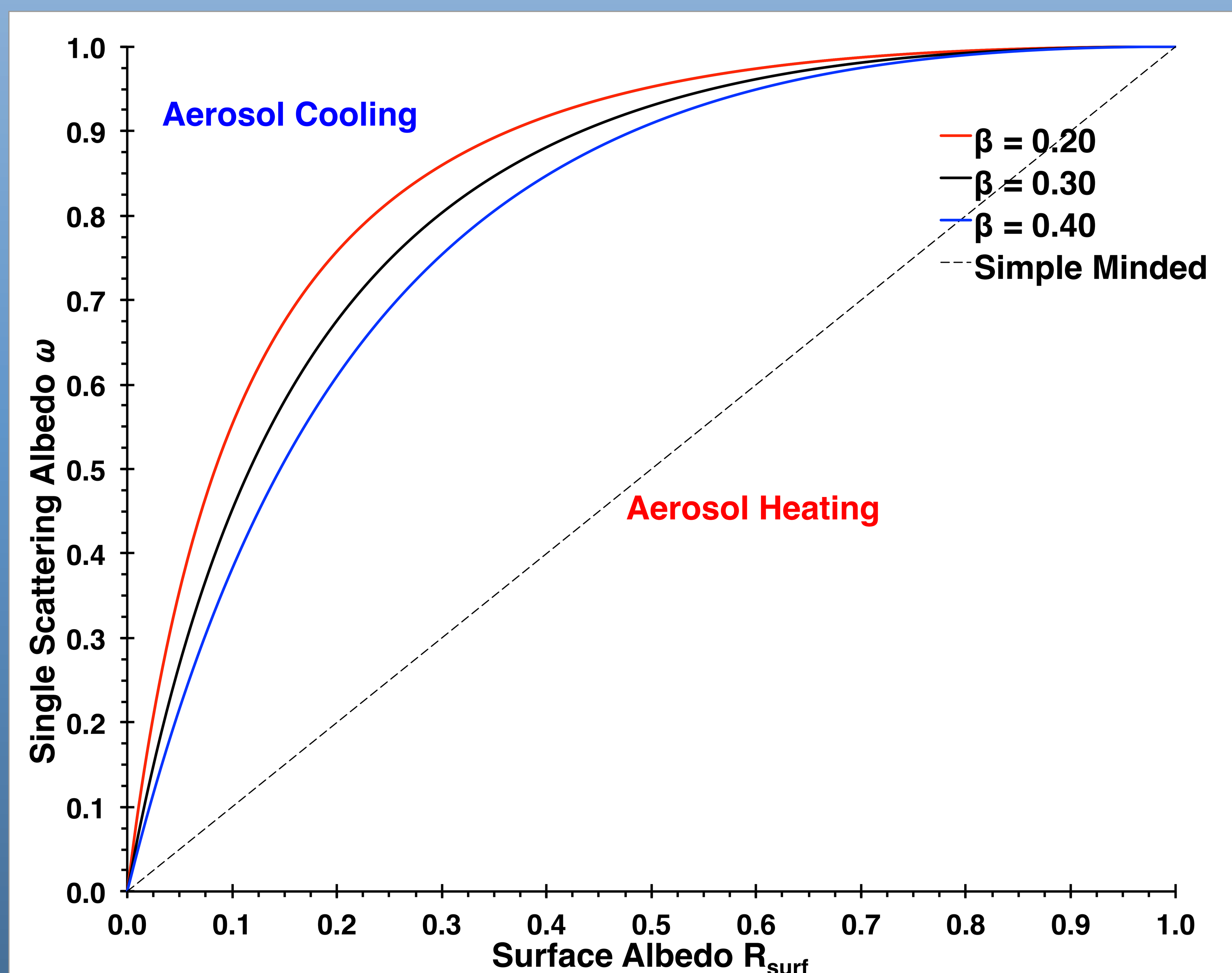
Heating or Cooling?

$\Delta F_{aer} = 0$ yields the boundary between Cooling and Heating depends only on ω, R_{surf}, and β

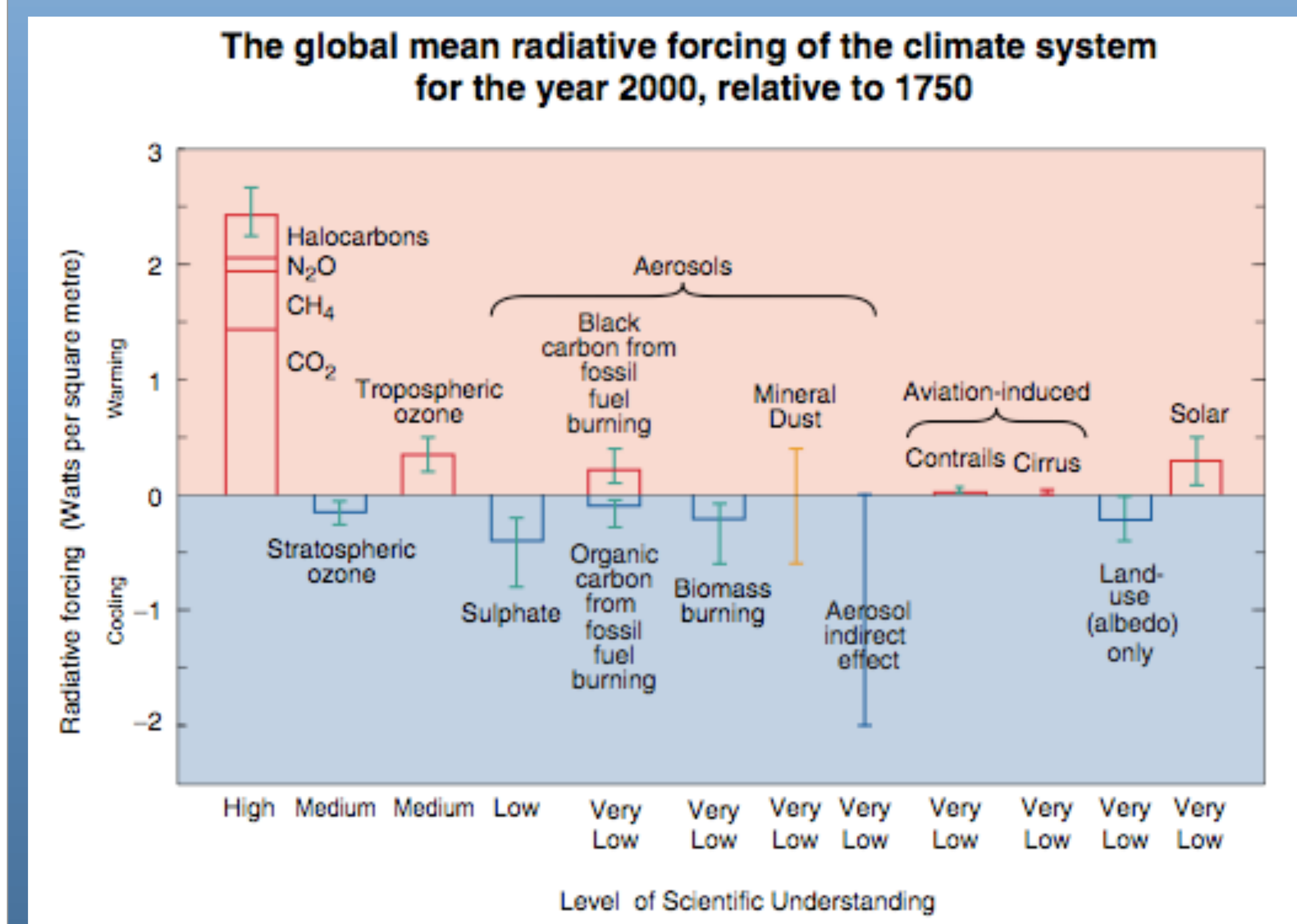
Atmospherically relevant upscatter fraction i.e., $0.2 < \beta < 0.4$ (Sheridan & Ogren; 1999)

Assumption of Henyey-Greenstein phase function

"Simple Minded" doesn't take multiple interactions into account



Importance of Aerosol Forcing



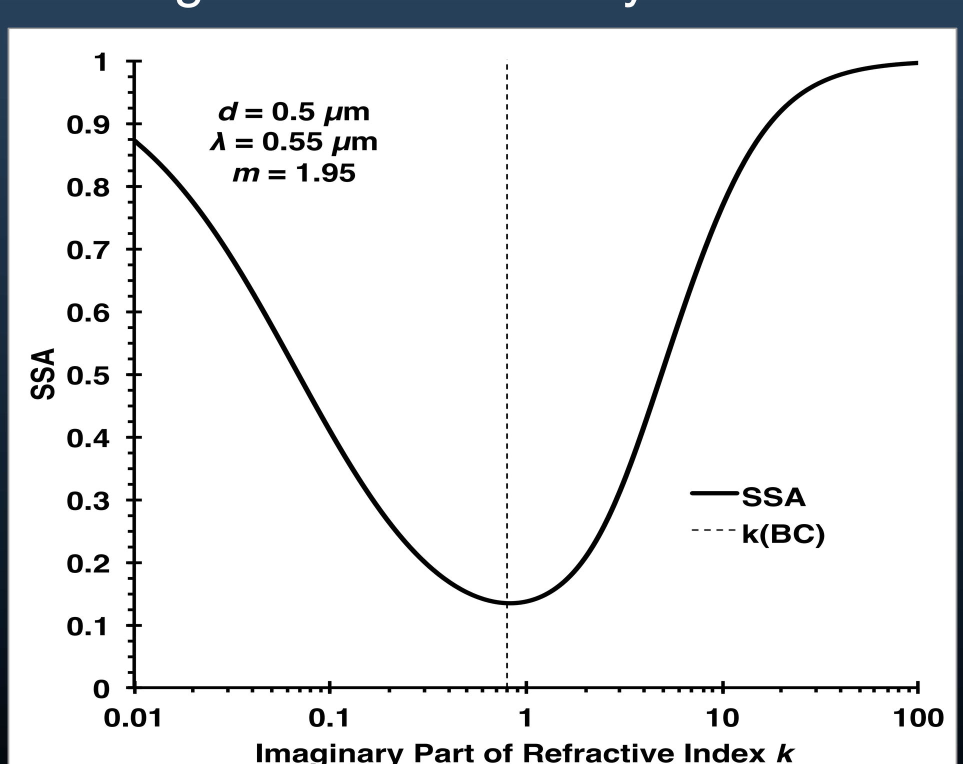
What Determines Albedo?

1) Material Properties

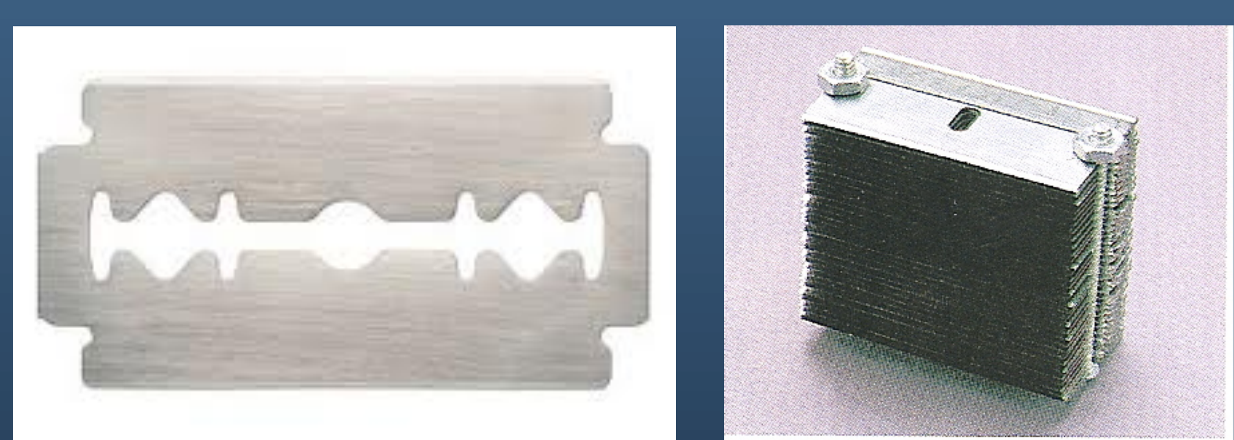
Complex Refractive Index

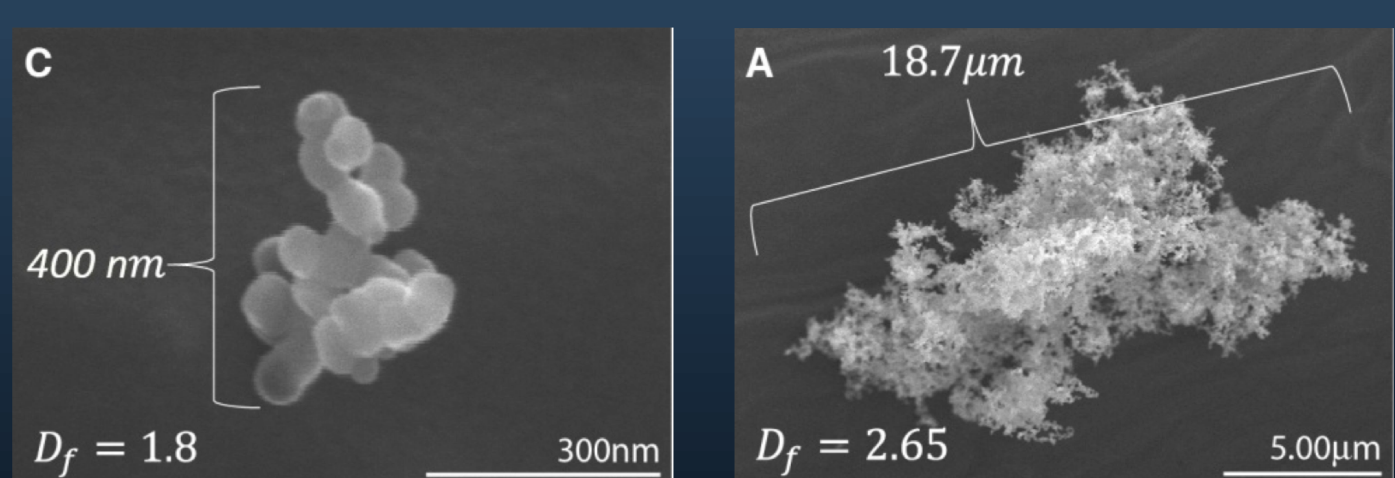
$m = n + ik$

For BC: $n = 1.95$ $k = 0.79$
Independent of wavelength in the visible
$K = 0 \Rightarrow$ no absorption
Bulk Absorption Coefficient $\alpha_{abs} = 4\pi\, k/\lambda$
Penetration Depth $1/\alpha_{abs} \sim 55$ nm
But larger k doesn't always reduce SSA

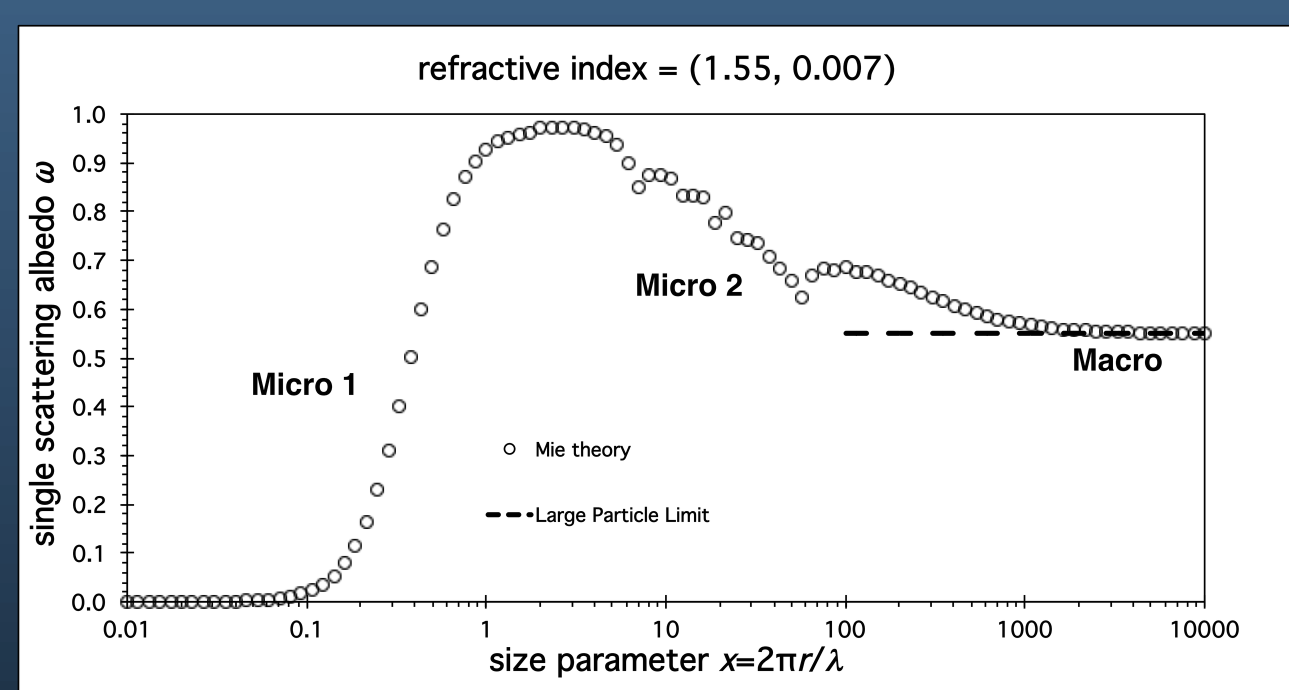


2) Morphology





3) Size



Macroscopic: Albedo Independent of Size

Microscopic 1: Albedo Increases with Size

Microscopic 2: Albedo Decreases with Size

Reference: Chýlek, P., and J. Wong (1995). Effect of Absorbing Aerosol on Global Radiation Budget. *Geophys. Res. Lett.*, **22**, 929-931.