Effect of Sub-pixel Clouds and Aerosols on the retrieval of Trace Gases

Pawan K. Bhartia & Joanna Joiner
Laboratory for Atmospheres
NASA Goddard Space Flight Center
Greenbelt, Maryland, USA

Effect of Clouds on the Retrieval of BL Trace Gas column

$$\hat{\mathrm{N}} = \frac{\mathrm{SCD}}{\mathrm{AMF}}; \quad AMF = (1 - w) * AMF_{clear} + w * AMF_{cloud}$$

where, w is the "cloud fraction"

For clouds above polluted BL : $AMF_{cloud} \approx 0$

$$\hat{N} \approx \frac{SCD}{(1-w)} \frac{1}{AMF_{clear}}$$

- Since clouds are usually much brighter than the surrounding atmosphere w can be several times larger than the geometrical cloud fraction.
- 10% error in w can produce 10-100% error in the estimated vert. column depending upon w.
- Cloud height is less important unless clouds are inside the BL.

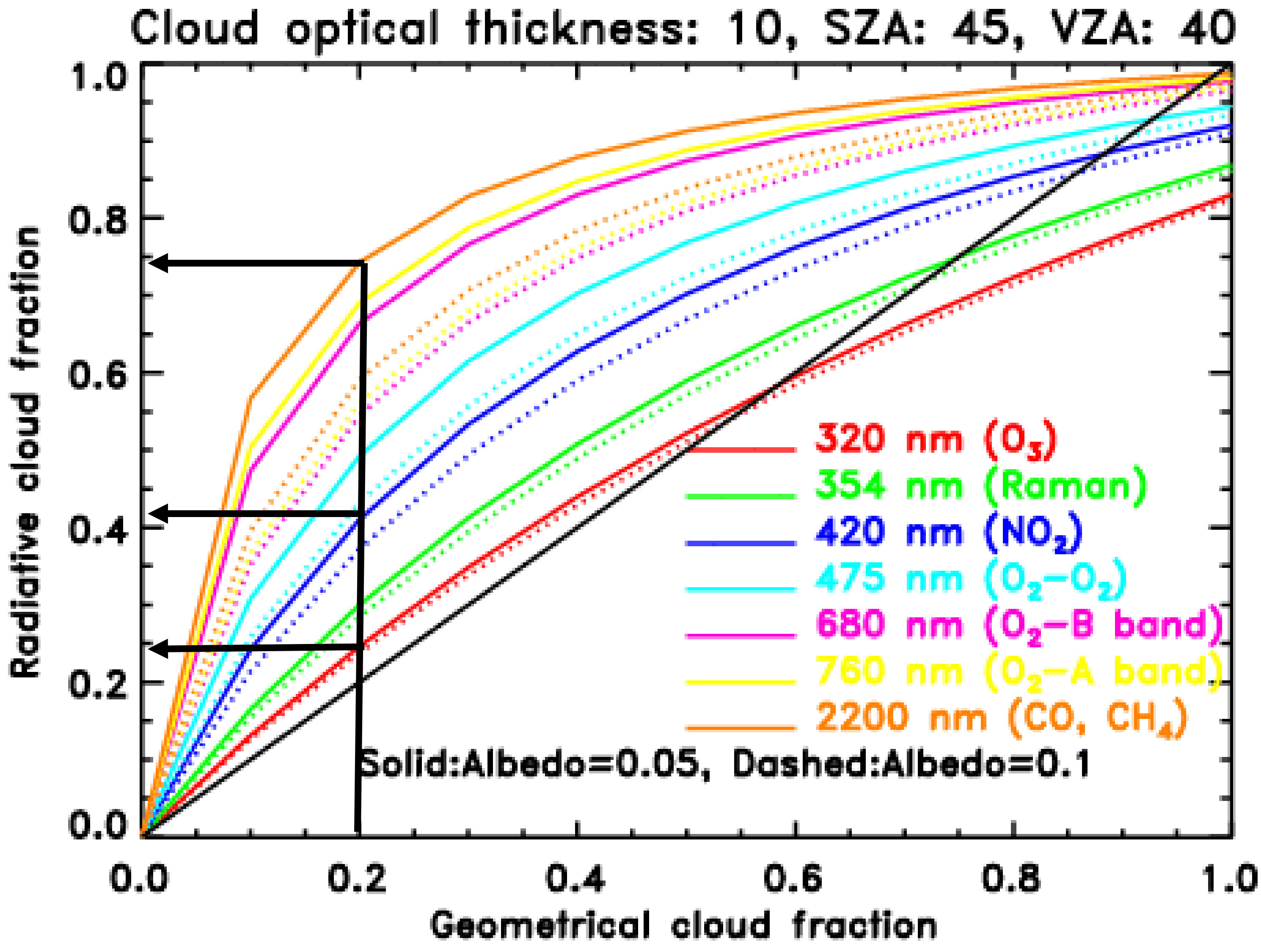
What is “Cloud Fraction”?

- For trace gas measurement at reflected λs it is the fraction of the measured radiation that comes from clouds (not including below cloud radiance that propagates thru clouds).
  - The OMI team calls it Cloud Radiance Fraction or Radiative Cloud Fraction (w).
- Formally, $w=f_g*\rho_c/\rho_m$

where f_g is the geometrical cloud fraction, ρ_c is the reflectance of the “bare” cloud, and ρ_m is the TOA reflectance corrected for atm absorption.

Cloud Radiance Fraction varies with λ

Rayleigh scattering effect on w



A Simple Method to Calculate w

Using Mie theory it can be shown that w varies linearly with ρ_{clear}/ρ_m

Applying boundary conditions:

$$w = \left(\frac{\rho_m - \rho_{clear}}{\rho_m^* - \rho_{clear}}\right)\left(\frac{\rho_m^*}{\rho_m}\right)$$

where, ρ_m^* is the "critical" TOA reflectance above which $w = 1$

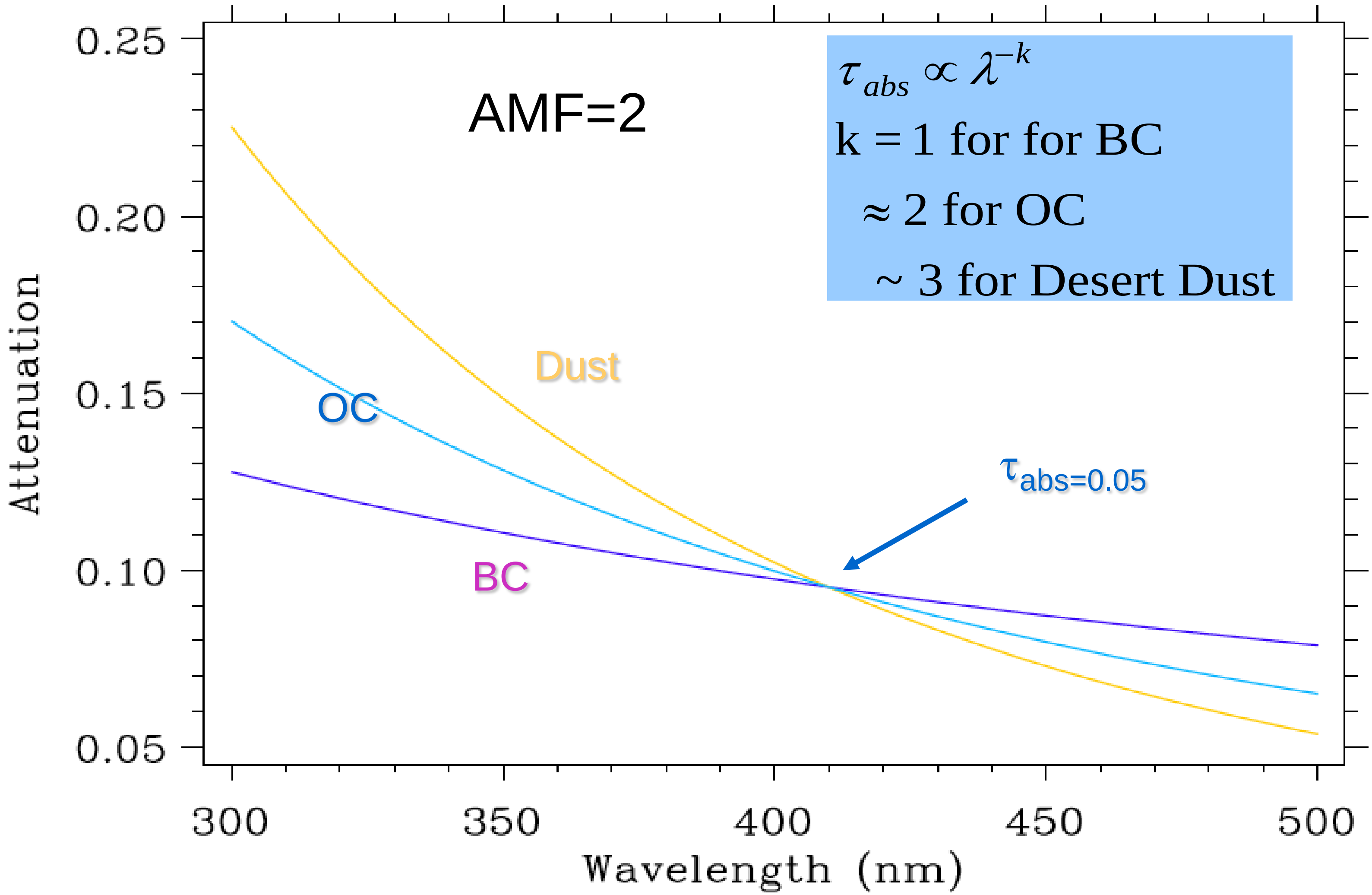
Since $\rho_m^* >> \rho_{clear}$, w is insenstive to ρ_m^*

In the TOMS and OMI algorithms ρ^*_m is calculated assuming an 80% reflecting Lambertian cloud. The results agree well with Mie theory.

Correction for Aerosols

- OMI method of calculating w accounts for non-absorbing aerosols of any kind.
- If aerosols have absorption, ρ_{clear} is overestimated, causing w to be underestimated.
  - the effect is worse in the UV than in the visible
  - the effect is worse for elevated aerosols
  - the effect is worse over brighter surfaces
- UV absorbing aerosol index (UV-AAI) can be used to develop a correction.

Reduction in w by Aerosol Absorption

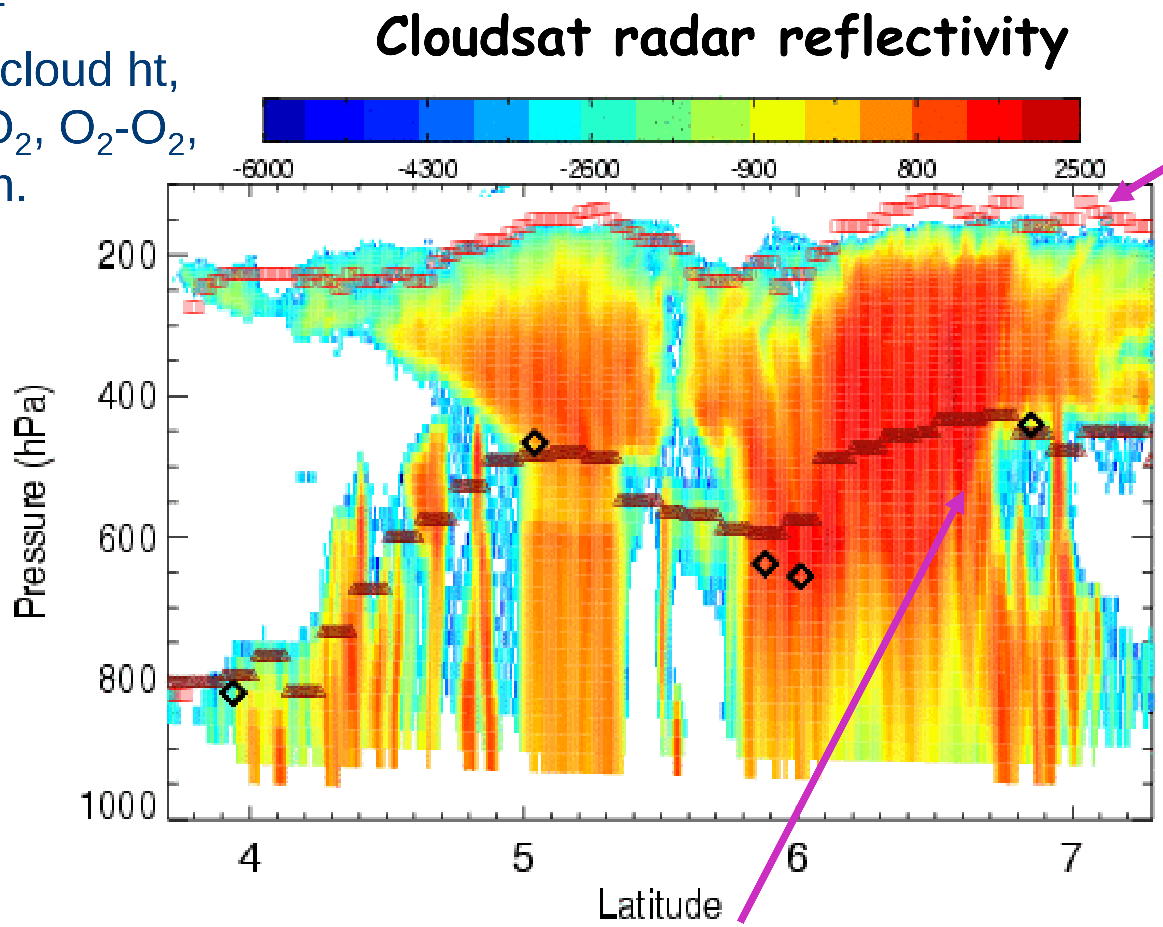


What About Cloud height?

- At reflected wavelengths sunlight penetrates into clouds and passes through most types of clouds.
  - Hence trace gas absorption is affected by cloud vertical structure. Cloud/aerosol mixed scenes can produce complicated effects.
- Concept of Optical Centroid Pressure (OCP) has been developed to account for this complexity.
  - The concept is accurate only if the trace gas is well mixed between the scattering layers, but is ALWAYS more accurate than assuming cloud-top pressure to estimate AMF.

Multi-phase/Multi-layer Cloud Effects

There are several methods of estimating cloud ht, e.g., TIR, O_2, O_2-O_2, and Raman.



MODIS cloud-top press is insensitive to cloud vertical structure

Cloud Optical Centroid press calculated using OMI-measured Rot Raman Scattering is sensitive to cloud vert structure (ref : Vasilkov *et al*.,JGR, '08)

Cloud OCP Retrieval Methods

- OMI uses Rotational Raman scattering @350 nm and O_2-O_2 absorption @477 nm to estimate OCP.
  - Both methods agree well with Cloudsat-derived OCP when w>0.5.
  - Random and systematic errors in OCP increase as 1/w for small w.
  - Both methods overestimate OCP when w is small.

Retrieved BL trace gas columns are probably most accurate when 0.3<w<0.7

Summary

- BL trace gas retrieval requires accurate knowledge of Cloud Radiance Fraction (w).
  - A simple method to calculate w, developed independently at NASA and KNMI, works very well, but correction for absorbing aerosols needs to be developed.
- To estimate the AMF it is far better to use OCP than the cloud-top pressure.
  - The two OMI methods for estimating OCP underestimate the OCP of clouds and aerosols for $w<0.5$.
- Aerosol and cloud mixed scenes present a significant challenge.
  - Currently, there is no good method to handle them.