

Why do we use Lambertian clouds?

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Overview

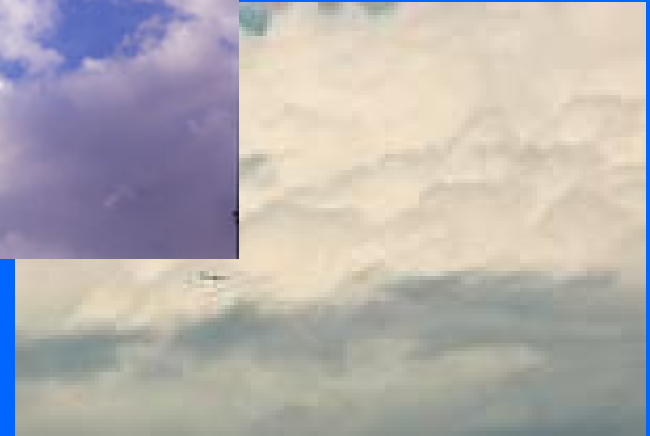
- Why Lambertian clouds in trace gas retrievals ?
- How accurate are Lambertian clouds?
- Effects of clouds on the depth of gaseous absorption lines.
- Sensitivity of tropospheric trace gas retrievals in the presence of clouds.

Rationale of Lambertian cloud model: Stammes et al., JGR, 2008

Clouds in trace gas satellite data

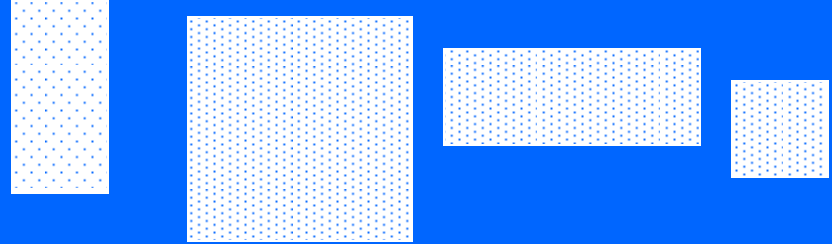
- UV-vis spectrometers have pixel sizes of order $100 \times 100 \text{ km}^2$ (GOME-1) to $20 \times 20 \text{ km}^2$ (OMI):
so clouds are not resolved > sub-pixel cloudiness
 - 95 % of pixels is cloudy for $100 \times 100 \text{ km}^2$ pixels
 - 85 % of pixels is cloudy for $10 \times 10 \text{ km}^2$ pixels
(Krijger et al., 2007, ACP)
- > Cloud detection and cloud correction are necessary elements of trace gas retrievals.

How to measure clouds?



Cloud models

- 3D-shaped scattering clouds



› *too many free parameters, too complicated RT*

- 1D-shaped scattering clouds



› *this is our benchmark*

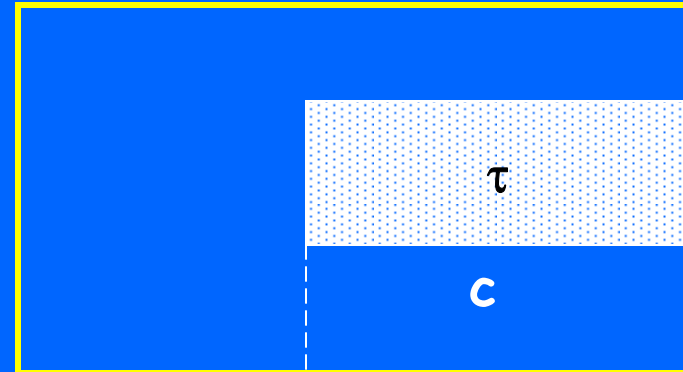
- Lambertian clouds (clouds as a white surface)

› *"All other things being equal, the simplest solution is the best"*
(William of Ockham, ca. 1285-1349)

Approximating scattering clouds by Lambertian clouds

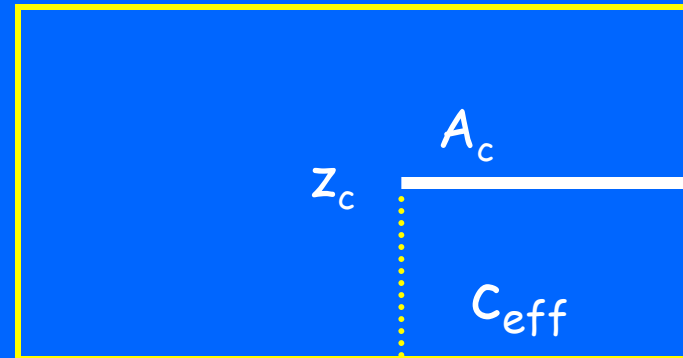
Scattering cloud (1D) parameters:

- Geometric cloud fraction: c
- Optical thickness: τ
- Cloud top height
- Cloud bottom height
- Cloud particle phase function
- Cloud extinction vertical profile



Lambertian cloud parameters:

- Effective cloud fraction: c_{eff}
- Cloud height: z_c
- Cloud albedo: A_c (*fixed*)

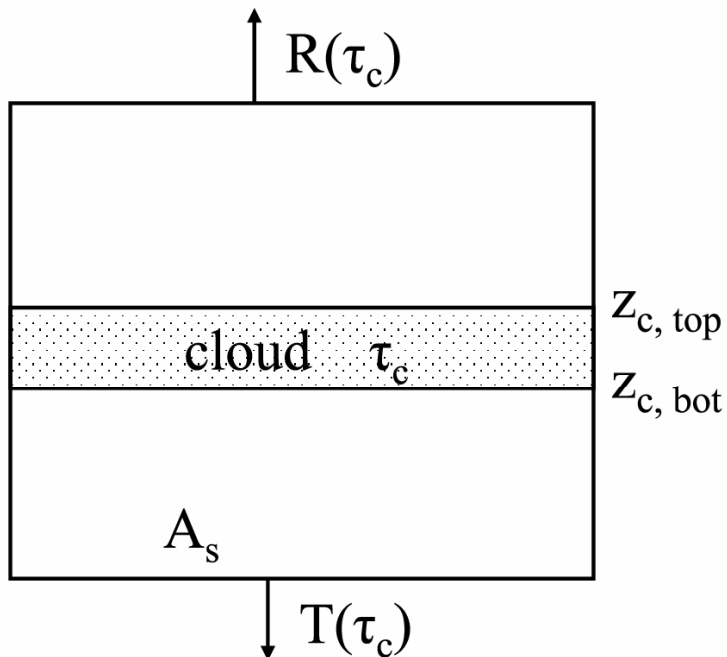


Retrieval of *two* Lambertian cloud parameters, c_{eff} and z_c , by fitting the O_2 A-band at 760 nm or the O_2 - O_2 band at 477 nm

Scattering cloud ($c=1$)

$$R = R(\tau_c)$$

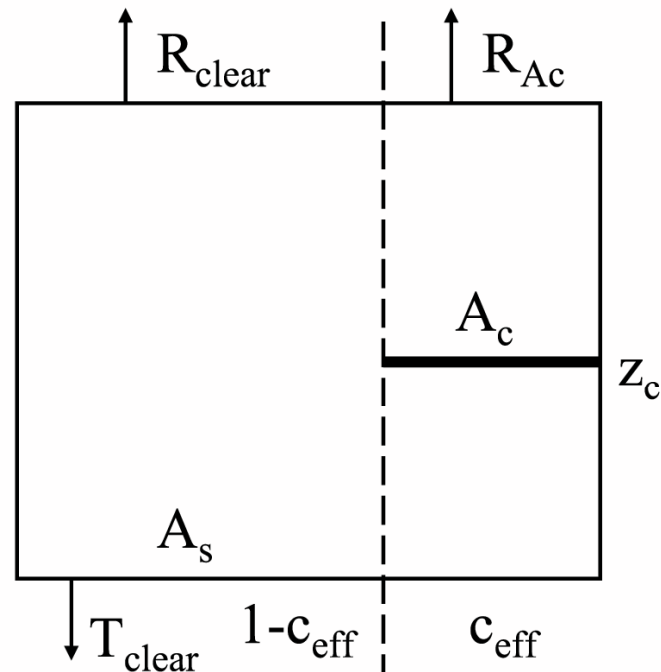
$$T = T(\tau_c)$$



Lambertian cloud

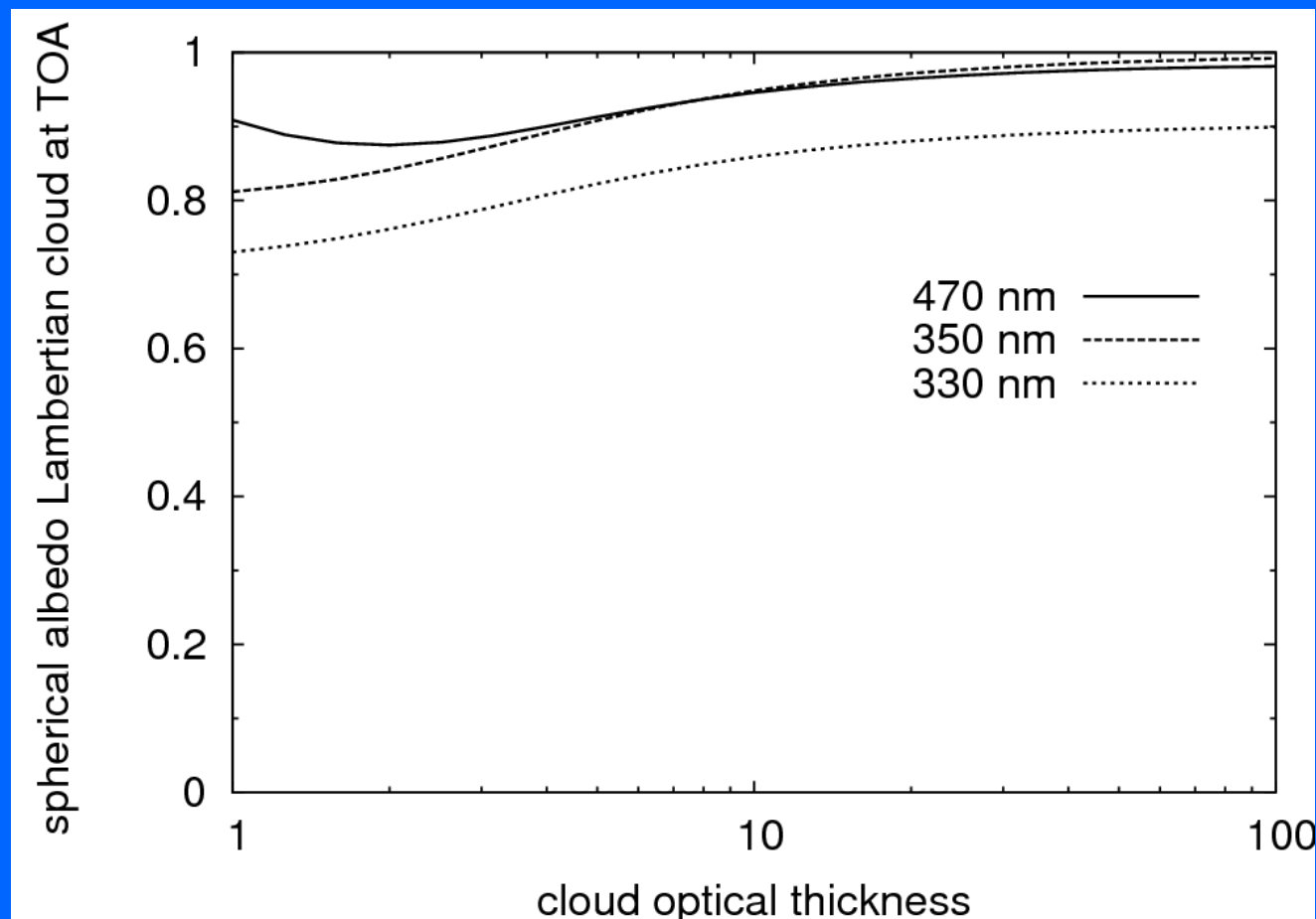
$$R = (1 - c_{\text{eff}})R_{\text{clear}} + c_{\text{eff}}R_{Ac}$$

$$T = (1 - c_{\text{eff}})T_{\text{clear}}$$



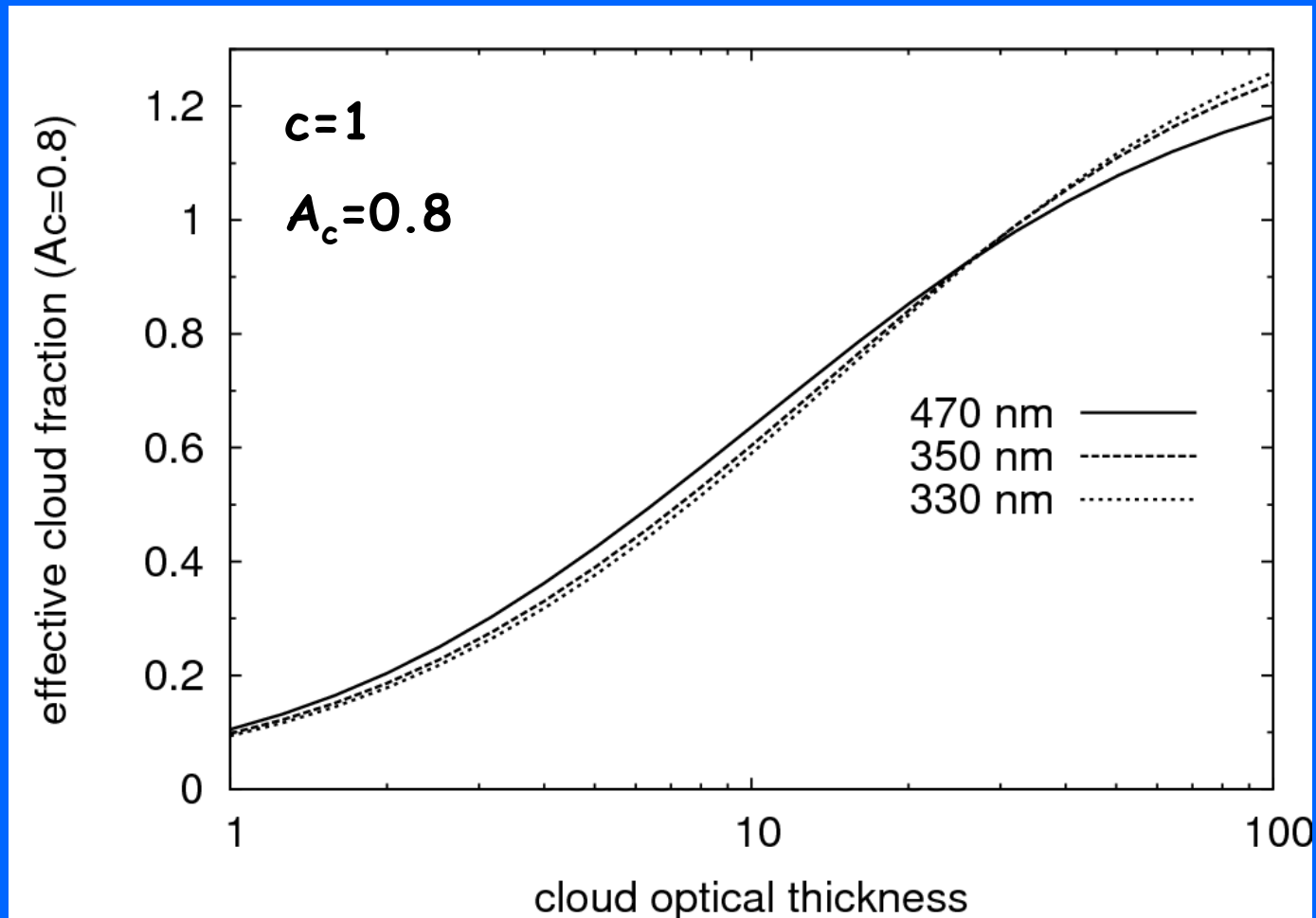
Optimal albedo of Lambertian cloud so that the reflection and transmission of a Lambertian cloud pixel is the same as that of a scattering cloud pixel

$$\Rightarrow A_c = 0.8 - 1.0$$

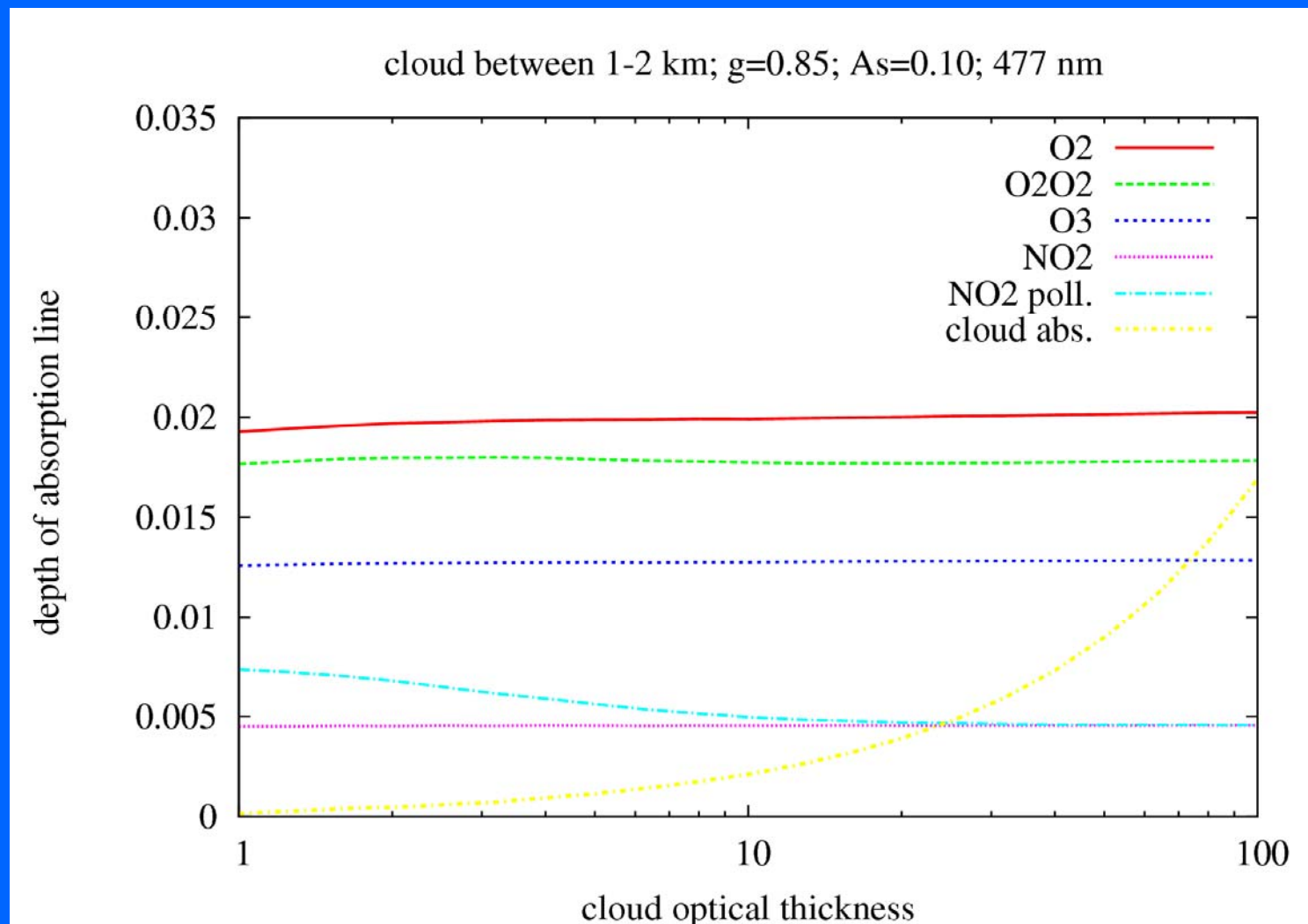


Effective cloud fraction

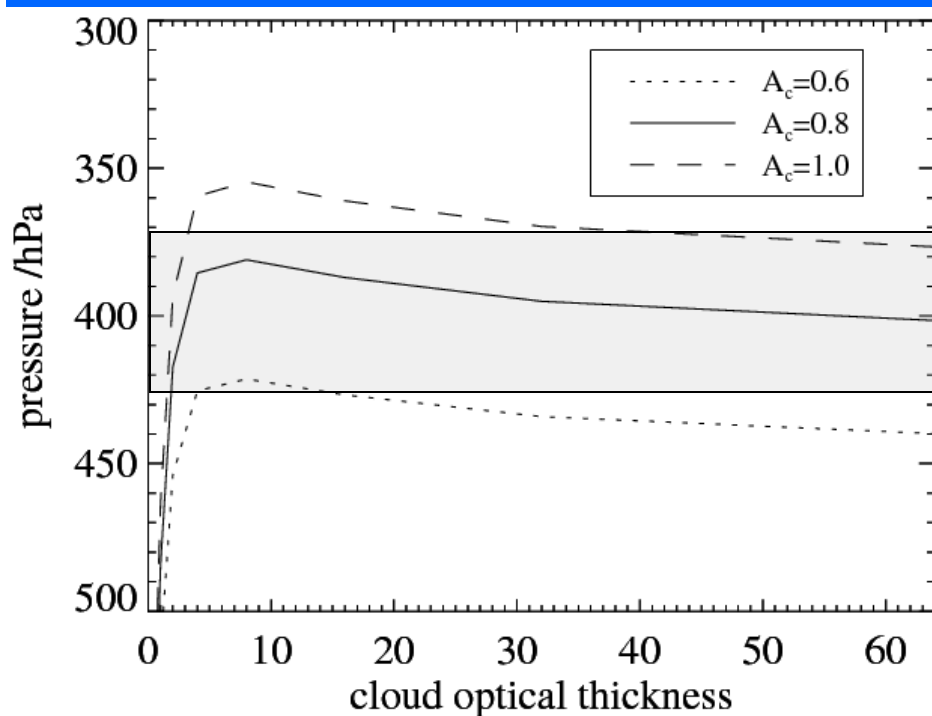
$$c_{\text{eff}} = c (R(\tau_c) - R_{\text{clear}}) / (R_{A_c} - R_{\text{clear}}) \cong c R(\tau_c) / A_c$$



Relative depth of gaseous absorption bands for scenes with scattering clouds



Error in ozone column retrieval due to Lambertian cloud model

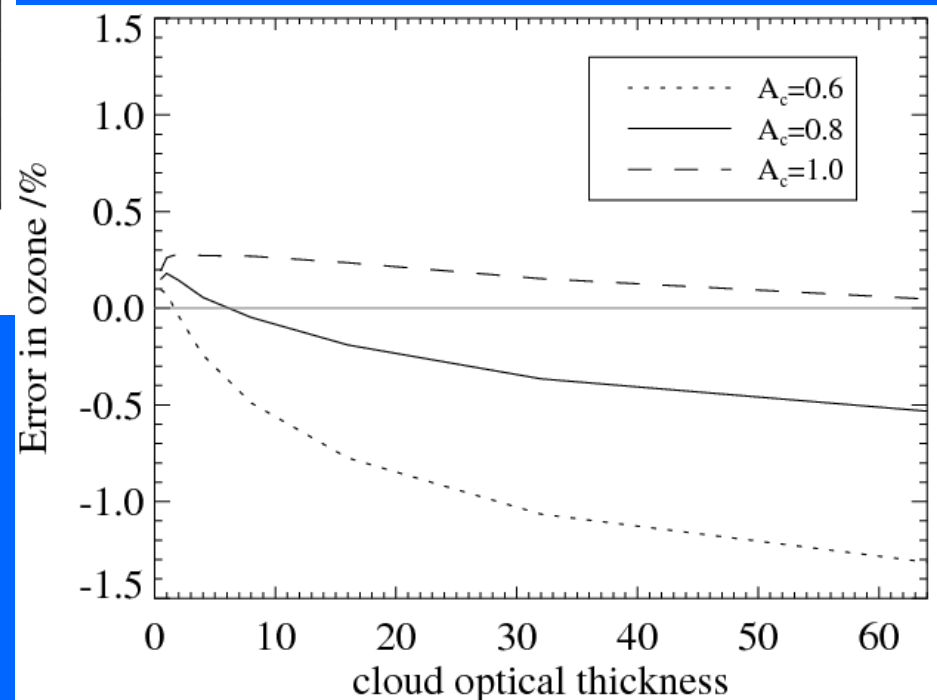


< Retrieved Lambertian cloud height using O2-O2

O2 cloud pressure with $A_c=0.8$ is about the middle of the cloud (Sneep et al., JGR, 2008)

Error in ozone column due to > Lambertian cloud instead of scattering cloud

11

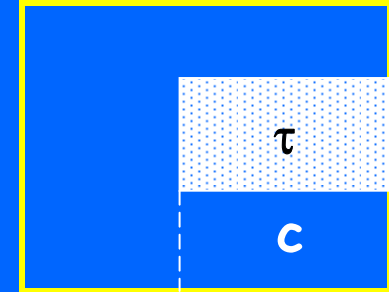


Tropospheric trace gas retrieval with clouds

AMF of scattering clouds:

$$M = (1 - w) M^{clear} + w M^{cloud}$$

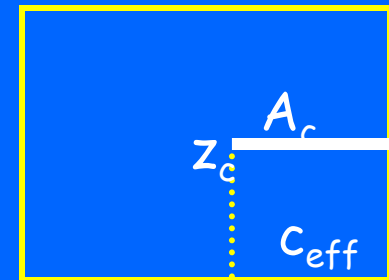
$$N = N_{slant} / M \quad w = \text{cloud radiance fraction}$$



AMF of Lambertian clouds:

$$M' = (1 - w) M^{clear} + w M_{lamb}^{cloud}$$

$$N = \frac{N_{slant} + w M_{lamb}^{cloud} N_{ghost}}{M'}$$



$$M_{lamb}^{cloud} \neq M^{cloud}$$

Simulations

Approach:

Calculate the column AMF, M , by integration of the "block AMF", $m(z)$ (in the DAK model):

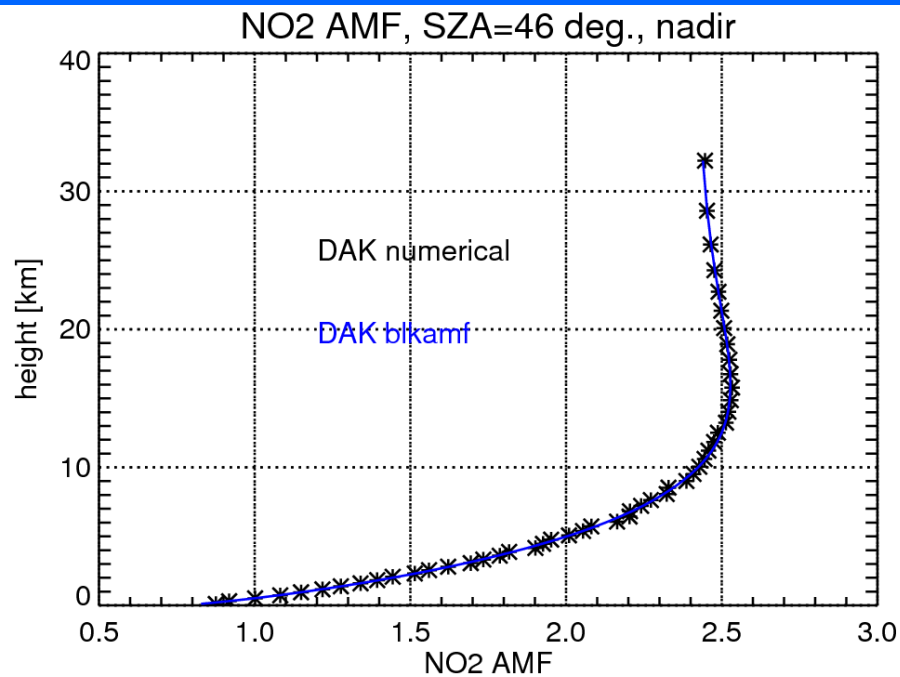
$$m(z, \lambda) = \frac{1}{R(\lambda)} \frac{d^2 R(\lambda)}{dk_{abs} dz} \quad (5)$$

$$M = \frac{\int_0^{\infty} m(z, \lambda) n(z) dz}{\int_0^{\infty} n(z) dz} \quad (6)$$

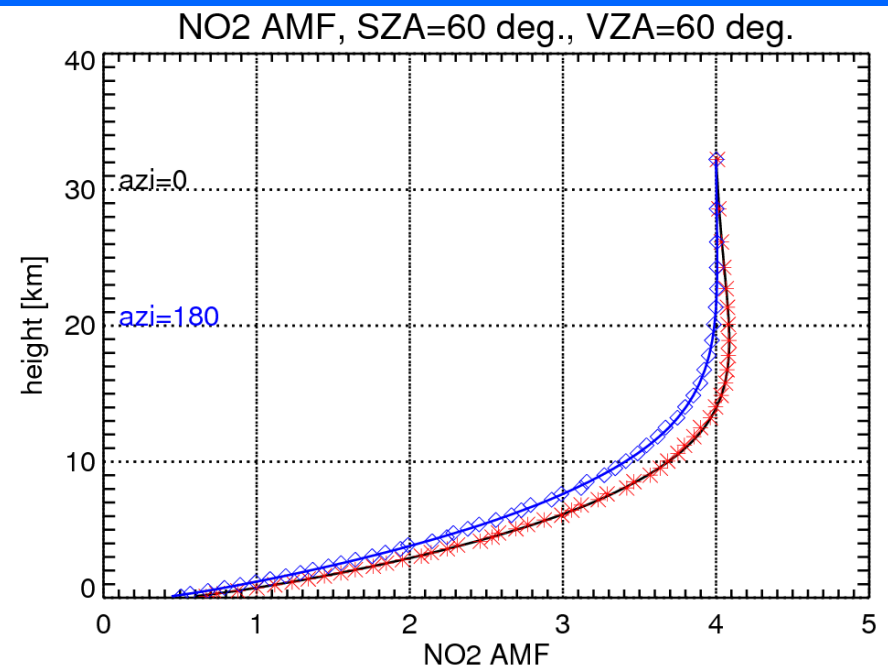
- Vertical column is known: N_v
- AMF is known: M (use scattering cloud model)
- Calculate slant column: $N_s = N_v M$
- (use Lambertian cloud model)
Calculate retrieved vertical column: N_{\dagger}
- Calculate O3 retrieval error:
 $(N_{\dagger} - N_v) / N_v$

Sensitivity to NO_2

- air mass factor profiles $m(z)$

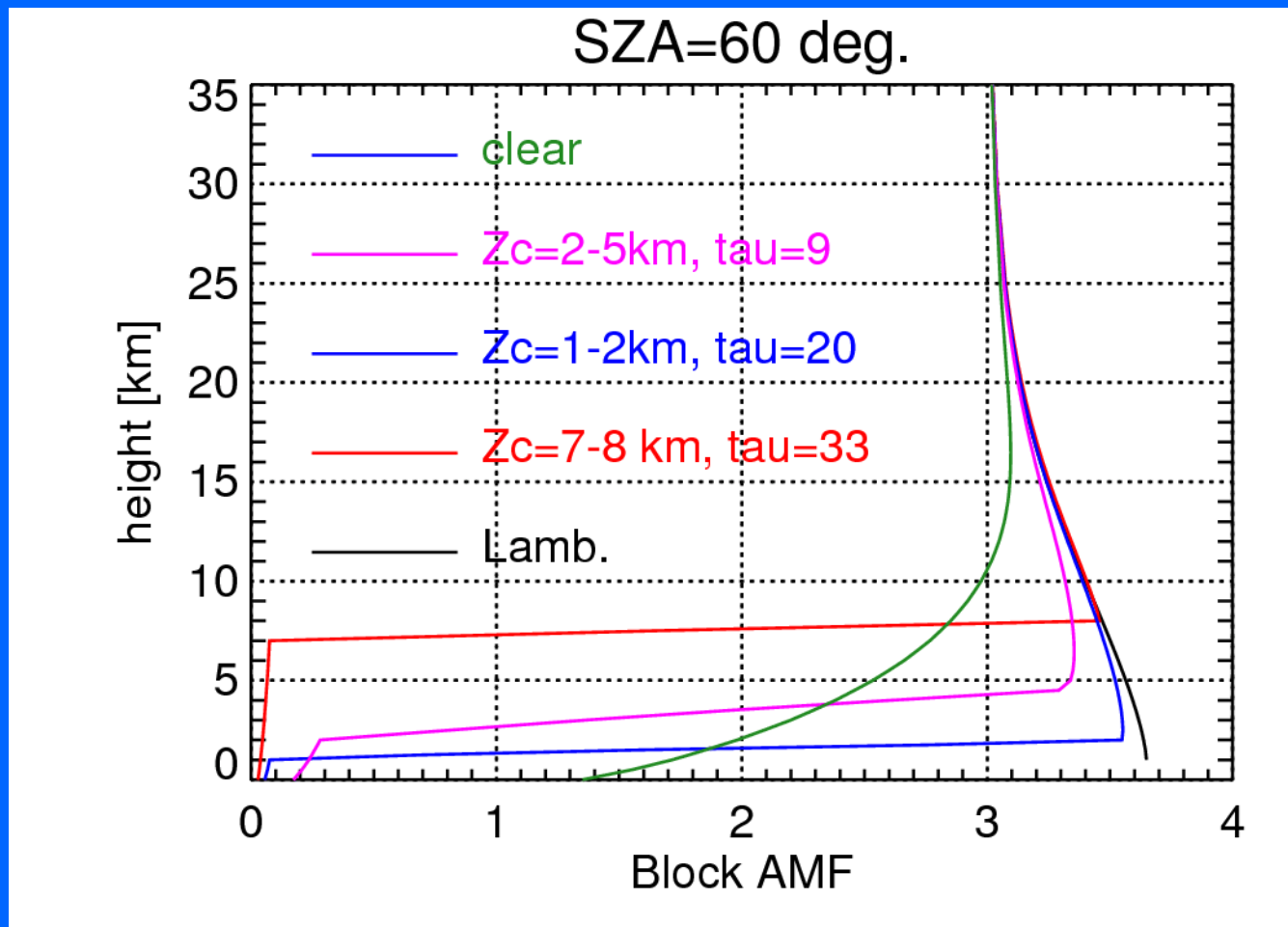


Clear sky, $A_s = 0.05$



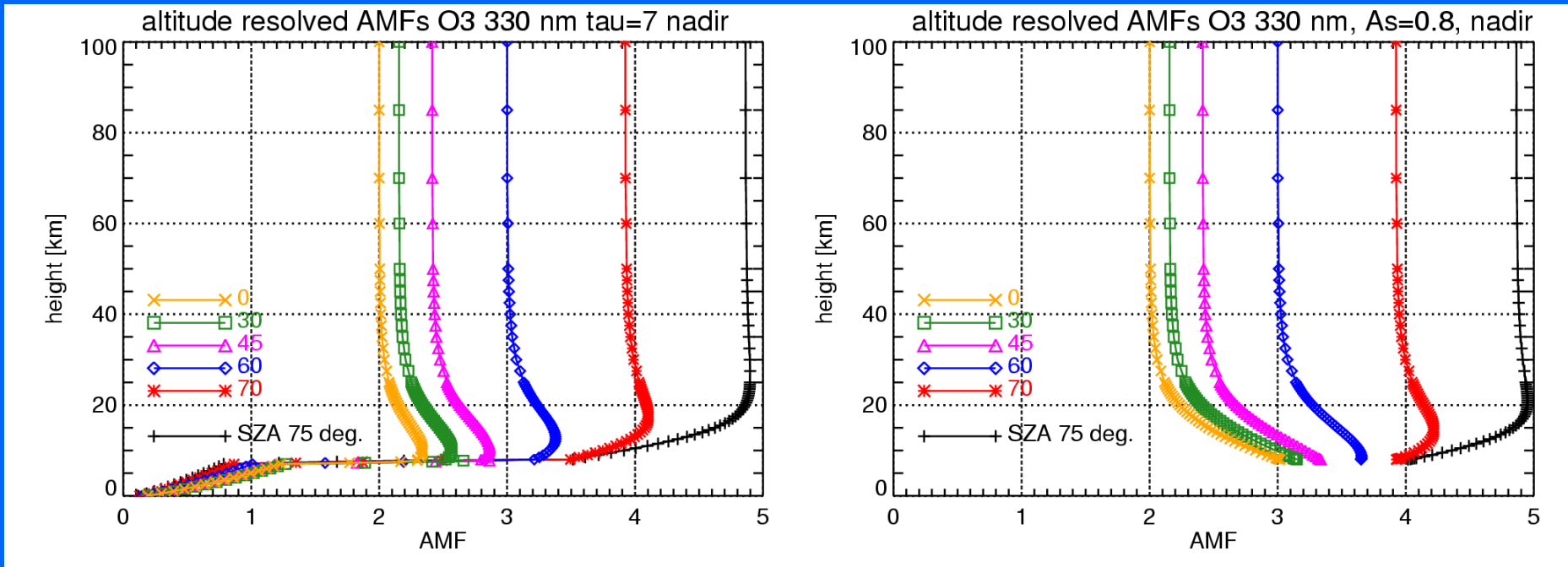
Comparison of analytic
and numeric NO₂ AMFs

Example of NO_2 sensitivity for scattering clouds and Lambertian cloud



Sensitivity to O_3

- air mass factor profiles $m(z)$

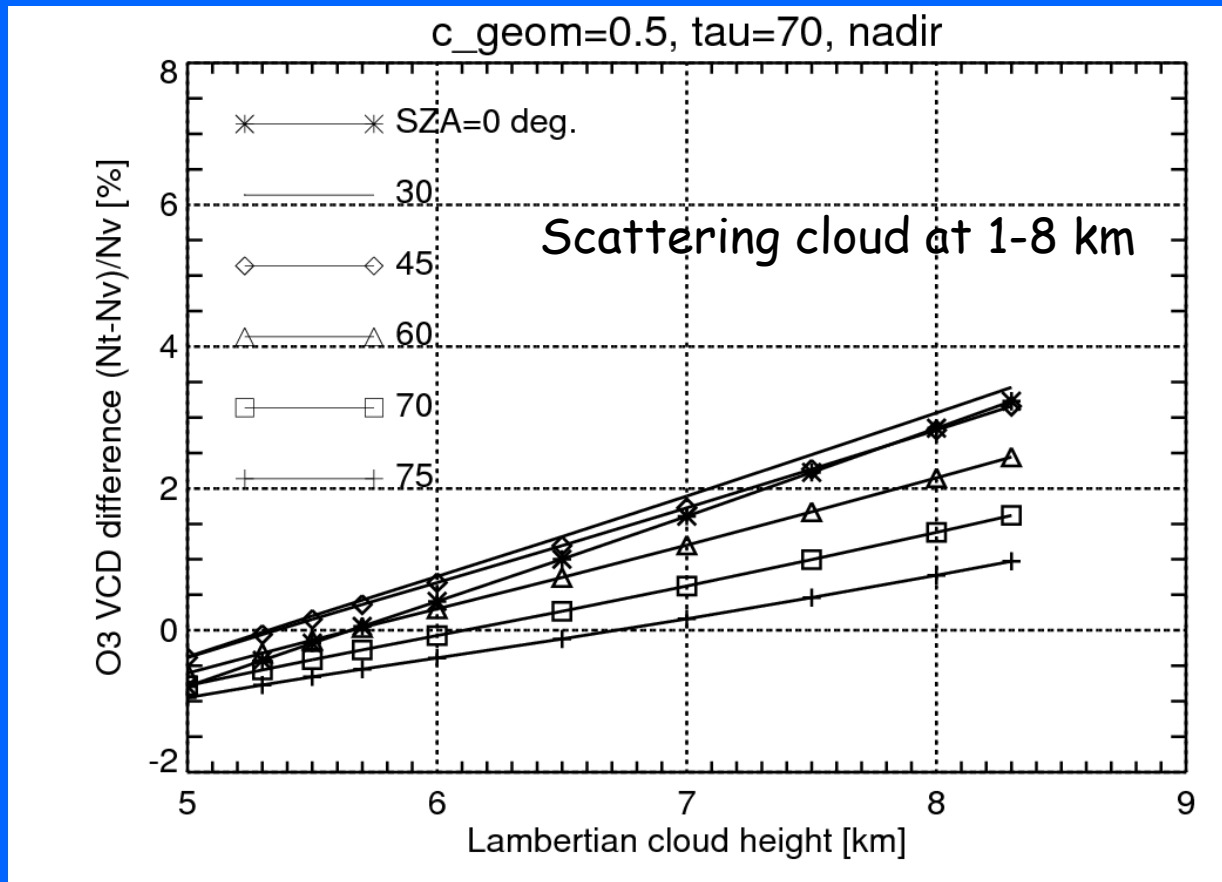


Mie scattering cloud at 7-8 km, $\tau_c=7$

Lambertian cloud, albedo 0.8

Use of a Lambertian cloud approximates the scattering cloud effect, but one has to add the O_3 column below the cloud.

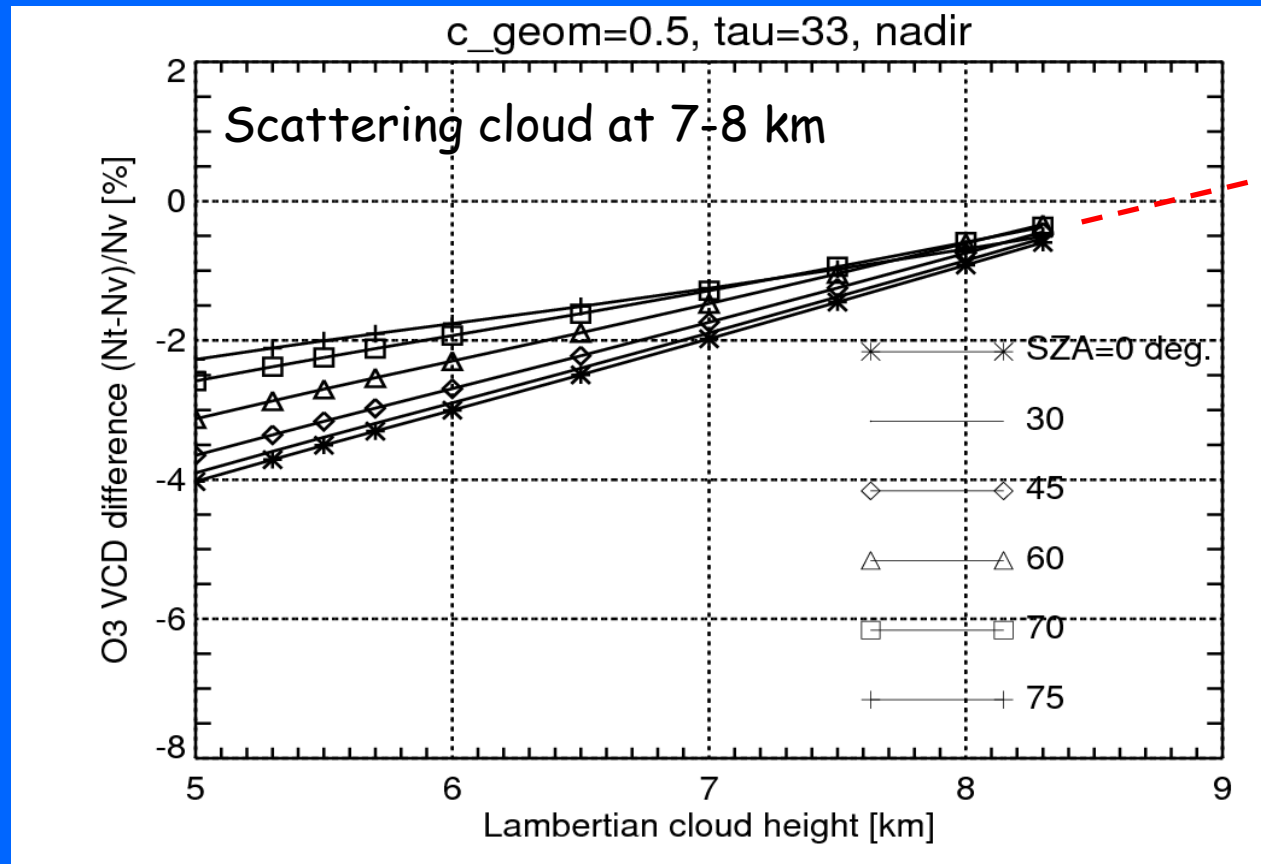
Error in O_3 column due to Lambertian cloud (1/3)



FRESCO cloud height is at 5.5 km

> Error in O_3 is close to 0 %.

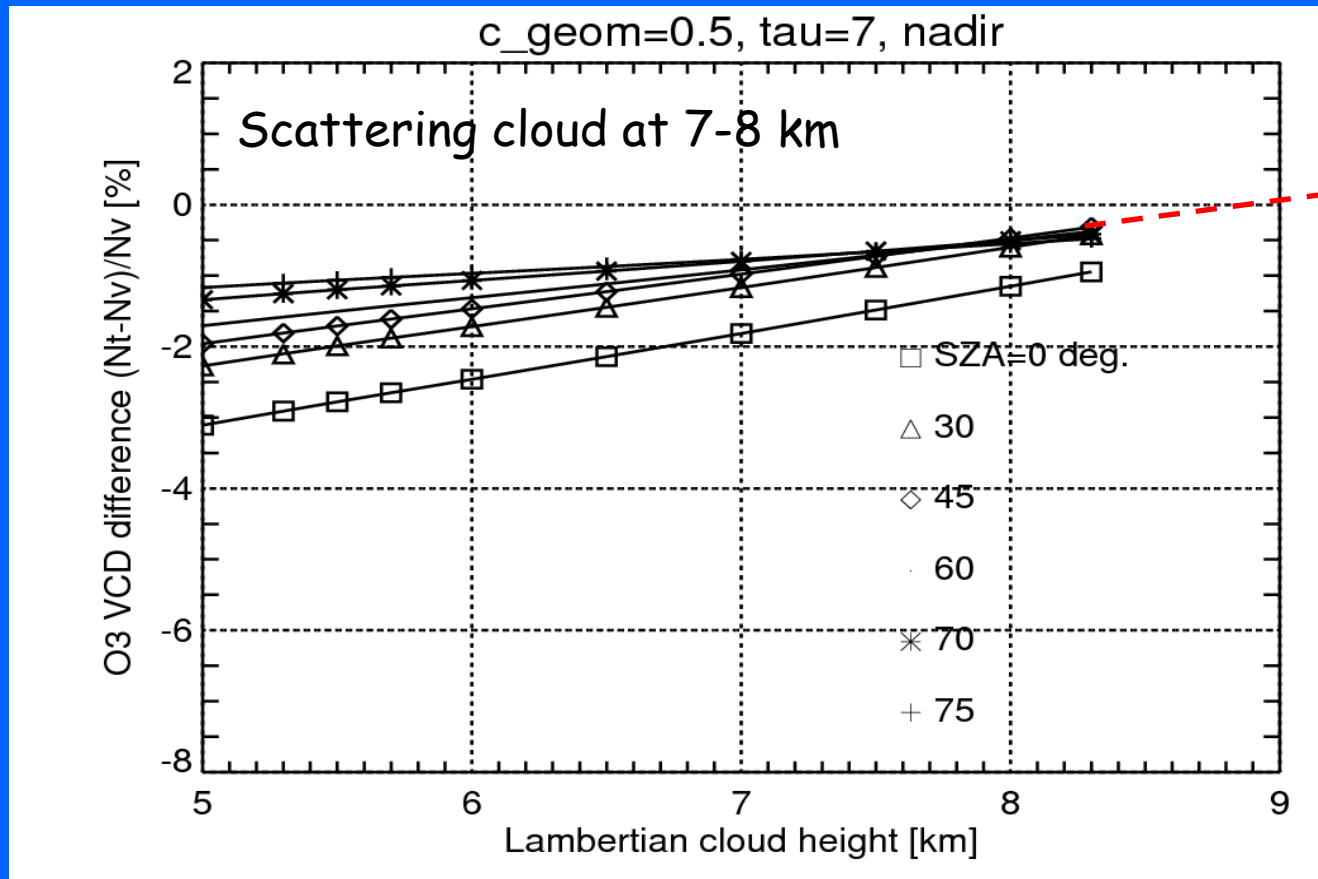
Error in O_3 column due to Lambertian cloud (2/3)



FRESCO cloud height is at ~7.5 km

> Error in O_3 is -1 % (underestimate)

Error in O_3 column due to Lambertian cloud (3/3)



Similar error as for $\tau_c=33$.

Lambertian cloud at higher altitude would give a smaller error in O_3 ; increase cloud albedo to 0.9 ?

Conclusions

- Lambertian clouds are a valid approximation of scattering clouds regarding their total reflection and transmission if the Lambertian cloud albedo is 0.8-1.0.
- The error in total ozone due to the Lambertian cloud assumption with $A_c=0.8$ is $< 1 \%$.
- The vertical profile of the air mass factor can be calculated analytically (Johan's formula) with DAK: this is fast and accurate.
- Limitations of the Lambertian cloud model:
 - Long photon paths due to reflections between cloud and surface (e.g. snow) cannot be simulated.
 - The SZA and VZA dependence is different from that of scattering clouds.
- Future: develop a simple scattering cloud model ?

