The effect of clouds on tropospheric NO$_2$ retrieval

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Overview

- Cloud effects on NO$_2$ retrieval
- Cloud correction in NO$_2$ retrieval
- Tropospheric NO$_2$ retrieval errors using Lambertian clouds
- NO$_2$ column differences using FRESCO and FRESCO+ cloud data
- Conclusions
Effects of clouds on trace gas retrieval

- Shielding effect
- Albedo effect
- In-cloud absorption
Approximating scattering clouds by Lambertian clouds

Scattering cloud parameters:
- Geometric cloud fraction: $c$
- Optical thickness: $\tau$
- Cloud top height
- Cloud bottom height

Lambertian cloud parameters:
- Cloud albedo: fixed to 0.8
- Effective cloud fraction: $c_{\text{eff}}$
- Cloud height (altitude): $z_c$

Retrieval of Lambertian cloud parameters by fitting the oxygen A-band using FRESCO:
$R_{\text{retr}} = R_{\text{meas}}$
FRESKO (SCIA) vs ARM cloud height

Good agreement.

FRESKO cloud height is mostly the middle of the cloud.

ARM (radar) cloud height is weighted with frequency of occurrence and thickness of cloud layers.

ARM=Atmospheric Radiation Measurement
Cloud correction in NO$_2$ retrieval

\[ M = wM_{\text{cloudy}} + (1 - w)M_{\text{clear}} \quad (1) \]

\[ w = \frac{f_c R_{\text{cloudy}}}{R} \quad (2) \]

\[ R = f_c R_{\text{cloudy}} + (1 - f_c)R_{\text{clear}} \quad (3) \]

cloud correction formula:

\[ N_t = \frac{N_s + wM_{\text{Lamb}}N_g}{M} \quad (4) \]

Simulation: $M$ is calculated with scattering cloud

Retrieval: $M$ is calculated with Lambertian cloud with $A_c=0.8$
Simulations

Approach:

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

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

(5)

$$M = \frac{\int_{0}^{\infty} m(z, \lambda)n(z)dz}{\int_{0}^{\infty} n(z)dz}$$

(6)

For the AMF of tropospheric NO$_2$, the integral is over 0-12 km.

• Vertical column is known: $N_v$
• AMF is known: $M$
• Calculate slant column: $N_s = N_v M$
• Calculate retrieved vertical column: $N_t$
• Calculate NO$_2$ retrieval error:
  $$(N_t - N_v)/N_v$$
  (for total or trop. column)
Three cloud cases for polluted NO$_2$ profile

NO$_2$ column densities:

$N_v=2.24E16$ molec/cm$^2$

$N_{trop}=1.68E16$ molec/cm$^2$
Background tropospheric NO₂

Error in total NO₂ column is ±1%

Nᵥ= 6.04 E+15 molec/cm²
Nᵥₜrop 4.01 E+14 molec/cm²
Tropospheric NO$_2$ error: high cloud case

$\text{c}_{\text{geom}} = 0.5 \quad \text{c}_{\text{eff}} = 0.33 \ (\text{SZA}=75^\circ) \quad 0.55 \ (\text{SZA}=0^\circ)$

Error in trop. NO$_2$ column is ± 5%
Tropospheric NO$_2$ error: middle cloud case

Error in trop. NO$_2$ column is ± 5-7 %

c$_{\text{geom}}$=0.5  
c$_{\text{eff}}$= 0.23 (SZA=75º)  
0.21 (SZA=0º)
Tropospheric NO\textsubscript{2} error: low cloud case

\[ c_{\text{geom}} = 0.5, \quad \text{c eff} = 0.35 \ (\text{SZA}=75^\circ) \]

\[ \text{c eff} = 0.38 \ (\text{SZA}=0^\circ) \]

Error in trop. NO\textsubscript{2} column is ± 10 %
Summary of simulation results (1/2)

- Errors in the (trop.) NO₂ column due to the Lambertian cloud model with Ac=0.8, (FRESCO) in the cloud correction (c_geom=0.5):

- **Background NO₂ profile:**
  error in the total NO₂ total column is only ± 1%.

- **Polluted NO₂ profile and high cloud:**
  error in trop. NO₂ column is small (± 5%), because these clouds only shield the tropospheric NO₂;
  retrieved cloud height is not very critical.

- **Polluted NO₂ profile and middle cloud:**
  error in trop. NO₂ column is ± 5-7%.

- **Polluted NO₂ profile and low cloud:**
  error in trop. NO₂ column is ± 10%;
  retrieved cloud height is critical!
Summary of the simulation results (2/2)

- The retrieved cloud height is about the optical middle of the cloud, but depends on SZA.
- This height gives mostly the smallest NO\textsubscript{2} retrieval error if there is NO\textsubscript{2} inside the cloud.
- For multi-layer clouds and NO\textsubscript{2} in the lower cloud layer, it is not possible to get the good cloud height for NO\textsubscript{2} correction; but if the top layer is optically thin, the retrieved cloud height is in the bottom layer.
- The given errors hold for \(c_{\text{geom}}=0.5\). The error does not strongly depend on geometric cloud fraction.
Effect of FRESCO+ on NO$_2$ from SCIAMACHY

- FRESCO+ is an improved version of FRESCO by addition of single Rayleigh scattering.
- FRESCO+ effective cloud fraction is about 0.01-0.02 larger than FRESCO effective cloud fraction.
- FRESCO+ cloud pressure is higher than in FRESCO: ~50 hPa in the global average
- FRESCO+ and FRESCO data are available at http://www.temis.nl
Difference in cloud pressure between FRESCO and FRESCO+ (SCIA)

On TEMIS webpage tropospheric NO$_2$ is reported for pixels with effective cloud fraction less than 0.3.
Conclusion on effect of FRESCO+ on trop. NO₂

- Using FRESCO+ in the cloud correction, the tropospheric NO₂ columns are lower than using FRESCO, especially for the low cloud scenes because the cloud is lower so the ghost column is smaller.
- For pixels without tropospheric NO₂ the total NO₂ columns are almost the same using FRESCO+ or FRESCO.
- Validation of cloud correction of trop. NO₂ is needed!
Back up slides
Tropospheric NO$_2$ error: high cloud case

$C_{\text{geom}} = 0.5$

$C_{\text{eff}} = 0.33$ \text{(SZA=75)}

0.55 \text{ (SZA=0)}

Error = +/-5%
Cloud GOME 20000105-0110
L1short data

gome_fresco_v45p.2000016_10stat.dat
ave_pc, ave_c, ave_pc1, ave_c1
675.660  0.342769  725.659  0.355749
Cloud TEMIS Go-v4, go-v5

20000105-0110

gome_fresco_v45t.2000016_10stat.dat

677.394  0.342492  728.508  0.355950
Cloud SCIA sc-v4, sc-v5

TEMIS data 20070101-0110 scia_fresco200701stat.dat

646.175   0.360213   712.755   0.379885
Cloud Sc-v4 sc-v5

no2track20070106-0110.pc_2d-log.eps
NO2 VCD trop.

VCD 1.04 3.24831
VCD 1.1 3.22453

diff.ghostcol <0.01
  >3
  =0