

# Simultaneous retrieval of atmospheric gases and cloud properties using the Ring effect

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## Introduction

The Ring effect describes the filling-in of solar and telluric absorption lines in spectra of the scattered sunlight, which is due to inelastic rotational Raman scattering (RRS) occurring on molecular oxygen and nitrogen in air. In spectra measured from space nadir sensors such as GOME and SCIAMACHY, the Ring effect is usually treated as an interfering process when retrieving trace gas columns. Modern radiative transport models, such as the LIDORT code developed at RT-Solutions, can accurately simulate the nadir backscattered radiance field including both elastic and inelastic RRS processes.

We present a simple method that uses both elastic and inelastic radiance closures to infer effective cloud fractions and cloud top heights, which are therefore determined in the same spectral interval as the trace gases. The method is applied to total ozone retrievals in the Huggins bands (325-335 nm). Preliminary results are compared with reference retrievals obtained using commonly available cloud products derived from O<sub>2</sub>-A band reflectivities.

## The GODFIT algorithm

- Direct fitting of simulated radiances to measured radiances by nadir UV satellite instruments (GOME, SCIAMACHY, GOME-2) (Lerot et al., 2010).
- Single-step fitting: neither slant columns nor air mass factors as in DOAS.
- Simulated radiances and weighting functions calculated « on-the-fly » with LIDORT v3.3 at all wavelengths
- T-shift procedure: the a priori T° profile is allowed to be uniformly shifted in the retrieval.
- The a priori O<sub>3</sub> profiles are provided by the total column-classified climatology TOMSv8.
- Fitting window: 325.0 - 335.0 nm
- Clouds are treated in the independent pixel approximation by assuming Lambertian clouds with a cloud top albedo of 0.8.

$$I_{tot}(\lambda) = (1 - CF) I_{clear}^{el}(\lambda) FF_{clear}(\lambda) + CF I_{cloud}^{el}(\lambda) FF_{cloud}(\lambda)$$

where CF is the effective cloud fraction adjusted within the fit procedure, FF are the filling-in factors calculated using the semi-empirical formulation.  $\rho_0$  within FF<sub>cloud</sub> is also adjusted and provides information on the cloud altitude.

- LIDORT-RRS is a radiative transfer model developed by RT Solutions Inc. including the rotational Raman scattering (Spurr et al., 2008). Using this model for simulating backscattered radiances leads to the most accurate results but is computationally intensive.
- A new formulation has been designed to correct the elastic radiances provided by LIDORT v3.3 for the Ring effect. This is based on concepts developed in Wagner et al. (2009), but also includes appropriate treatment of atmospheric absorption effects.

## Filling-in Factor

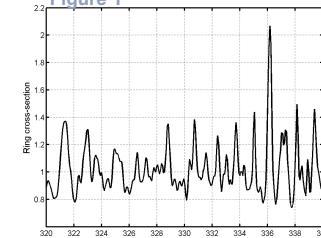
$$\frac{I(\lambda)}{I_0(\lambda)} = \frac{I_{el}(\lambda)}{I_0(\lambda)} \left\{ 1 + \rho_0 [\sigma_r \exp(\tau_{O3}(A_{tot}(\lambda) - A_{out}) - \tau_{O3}^{RRS} A_{in}) - 1] \right\}$$

where  
 I is the corrected radiance  
 I<sub>0</sub> is the solar irradiance  
 ρ<sub>0</sub> is the inelastic scattering probability  
 σ<sub>r</sub> is the Source Ring cross-section, calculated as in Fig. 1.  
 τ<sub>O3</sub> and τ<sub>O3</sub><sup>RRS</sup> are the vertical ozone optical depths based on regular, and RRS-smoothed cross-sections, respectively.  
 A<sub>tot</sub>, A<sub>in</sub> and A<sub>out</sub> are the air mass factors for the total light path and for the incoming and outgoing light paths.

- When ρ<sub>0</sub>, A<sub>out</sub> and A<sub>in</sub> are adjusted, the filling-in factors closely reproduce those provided by LIDORT-RRS as illustrated in Figs. 3a and 3b.
- Look-up tables of these three parameters have been generated for a set of representative observation conditions. For each cell in these LUTs, ρ<sub>0</sub>, A<sub>out</sub> and A<sub>in</sub> are derived from a fit procedure to the LIDORT-RRS filling factors. The LUTs have 6 dimensions: total O<sub>3</sub> column, solar zenith angle, viewing zenith angle, relative azimuth angle, surface albedo and surface height.

## Semi-empirical Ring correction

Figure 1

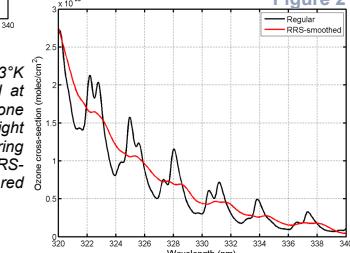


Source Ring cross-section  $\sigma_r$  at GOME resolution calculated as:

$$\sigma_r(\lambda) = \frac{I_0(\lambda) \otimes F(\lambda)}{I_0(\lambda)}$$

where  $F(\lambda)$  are the normalised rotational Raman cross-section of molecular N<sub>2</sub> and O<sub>2</sub> (Wagner et al., 2009).

Figure 2



Ozone absorption cross-section at 243°K from Daumont-Brion-Malicot degraded at GOME resolution. Part of the ozone absorption signal from the incoming light is smoothed by the inelastic scattering processes. The corresponding RRS-smoothed O<sub>3</sub> cross-section is the red curve and is calculated as:

$$\sigma_{O3}^{RRS}(\lambda) = \frac{(I_0(\lambda) \times \sigma_{O3}(\lambda)) \otimes F(\lambda)}{I_0(\lambda) \otimes F(\lambda)}$$

Figure 3a

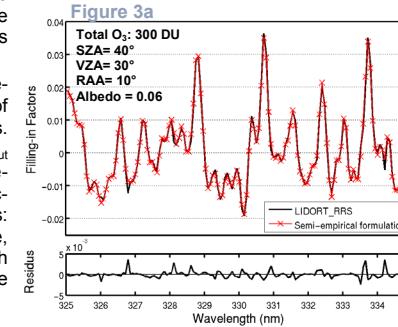
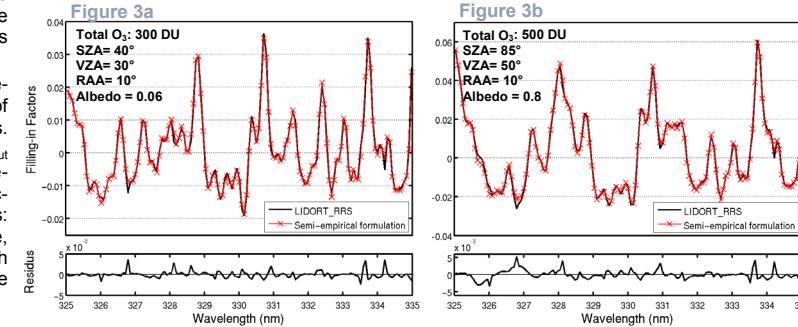


Figure 3b



Comparison of the semi-empirical filling-in factors and those from LIDORT-RRS in the O<sub>3</sub> fitting window for two different scenarios.

## Cloud parameter retrievals: preliminary results

Figure 4: Main dependences of the Ring coefficient ρ<sub>0</sub>

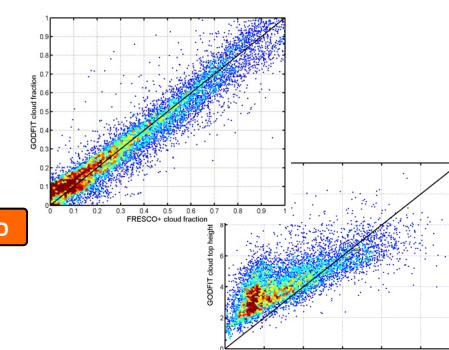
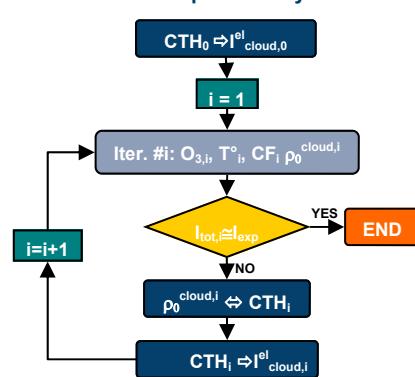
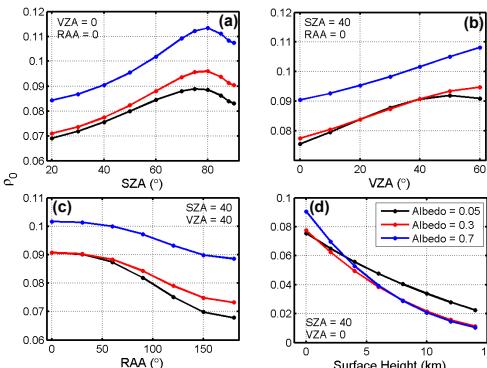


Figure 6: Comparison of the retrieved cloud fraction and cloud top height to FRESCO+ parameters for GOME data of 1st April 99. Cloud top heights are only compared for pixels

## Conclusions

- A new semi-empirical formulation to account for the inelastic Raman scattering in the total O<sub>3</sub> retrievals has been presented. The filling-in factors calculated using this formulation are in excellent agreement with filling-in factors calculated with LIDORT-RRS when three physical parameters are adjusted.
- Using look-up tables of these parameters for all observation conditions allows to have a fast and accurate Ring correction in the total O<sub>3</sub> retrievals.
- The strong dependence of the inelastic scattering probability (ρ<sub>0</sub>) with respect to the surface height (Fig. 4d) provides information about the cloud altitude when the corresponding parameter in the cloudy part of the simulated radiances is adjusted in the retrieval procedure.
- First comparisons of the retrieved cloud fraction and cloud top height with FRESCO+ parameters show reasonably good agreement.
- Currently, cloud altitudes are systematically overestimated for low cloud fractions (not shown here), which needs to be further investigated.

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References: Lerot et al., Int. J. Remote Sens., 31: 2, 543-550, 2010.

Spurr et al., JQSRT, 109, 404-425, 2008.

Wagner et al., Atmos. Meas. Tech., 2, 113-124, 2009.