Tropospheric ozone measurements with IASI/MetOp-A using a new self-adapting Tikhonov-Phillips altitude-dependent regularization

Maxim Eremenko (1), Marco Ridolfi (2), Luca Sgheri (3), Gaëlle Dufour (1), Juan Cuesta (1), Pasquale Sellitto (1), and Jean-Marie Flaud (1)

(1) Laboratoire Inter-universitaire des Systèmes Atmosphériques (LISA), UMR7583, Universités Paris-Est Créteil et Paris Diderot, CNRS, Créteil, France
(2) Dipartimento di Fisica e Astronomia, Università di Bologna, Italy
(3) Istituto per le Applicazioni del Calcolo, Firenze, Italy

Contact: maxim.eremenko@lisa.u-pec.fr

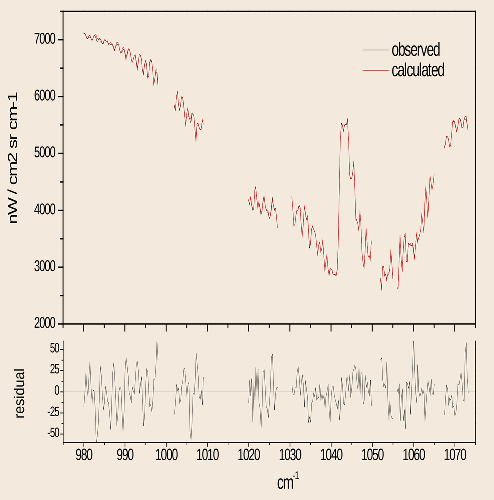
1. Retrieval Method

- Radiative transfer model **KOPRA** (Karlsruhe Optimised and Precise Radiative transfer Algorithm) + Inversion module **KOPRAFIT**
- A constrained least squares fit method using an **analytical altitude-dependent regularization** is used: combination of zero, first and second order Tikhonov constraints with altitude-dependent coefficients. The coefficients are optimized to both maximize the degrees of freedom (DOF) and to minimize the total error on the retrieved profile. All the details of the retrieval method are reported in [1].

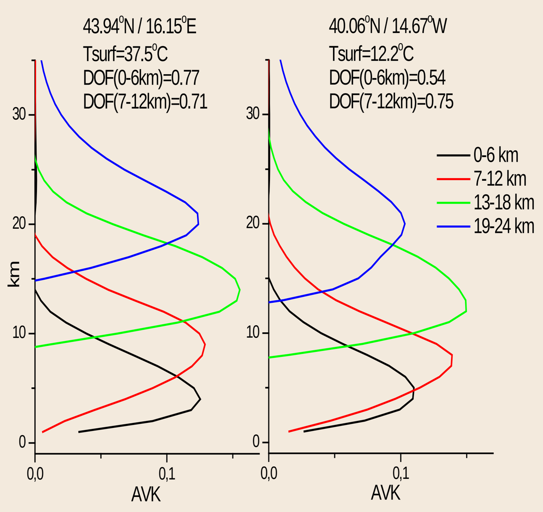
The analysis of IASI data is performed in three steps:

- retrieval of the effective surface temperature : selected windows between 800 and 950 cm^{-1}, emissivity equal to unity.
- retrieval of the atmospheric temperature profile from CO_2 lines in the 15 μm spectral region and using the ECMWF profiles as a priori.
- retrieval of the ozone profiles from seven spectral windows in the 975-1100 cm^{-1} region that avoid strong water vapor lines.

- Cloud filter + quality flags
- Calculation of the partial columns



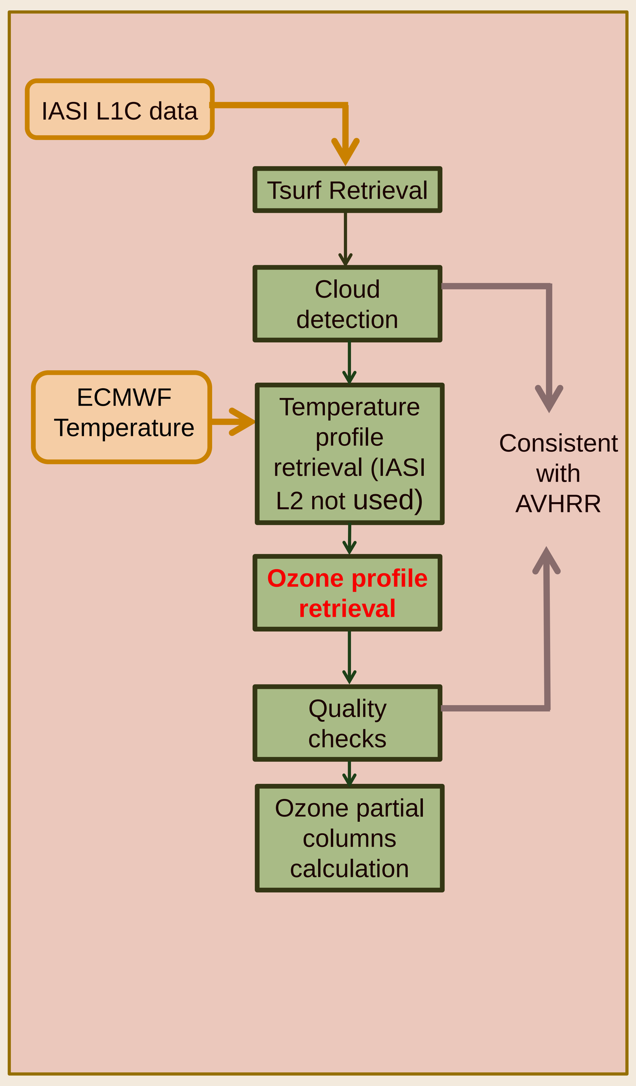
Spectral microwindows used for the ozone retrieval



Comparison of averaging kernels in partial column space for conditions of hot (left panel) and cold surface temperature (right panel).

[1] Eremenko et al., Geophys. Res. Lett., 35, L1885, 2008.

2. Data processing



3. Potential improvements

The constraint used for the retrievals is constant and based on the ozone climatology for the midlatitudes region. For atypical situations this constraint appears to be inadequate (too strong for the most favorable situations, too weak for the worst cases). Both situations lead to retrieval problems:

- **sensitivity of the retrieval profile** (particularly at the lower tropospheric layers) **could be maximized** when the conditions are favorable
- **oscillating profiles** when the constraint is too weak that are currently rejected by the quality filters **could be better controlled** and produce additional information.

In order to optimize the retrieval we explore the possibility to adjust the constraint to the real information included in each measurement which depends on the thermodynamical conditions (thermal contrast, tropopause height). A self-adapting and altitude-dependent regularization method for atmospheric profile retrievals [2] was implemented.

[2] Ridolfi et al., OPTICS EXPRESS, 19, No. 27, 2011

4. Self-adapting and altitude-dependent regularization

The iterative solution using the LISA retrieval method can be expressed as follow:

$$x_{i+1} = x_i + \left(K_i^T S_y^{-1} K_i + R\right)^{-1}\left[\left(K_i^T S_y^{-1}\left(y - f(x_i)\right) + R\left(x_a - x_i\right)\right)\right]$$

Where
x_a – the apriori solution vector
x_i – the solution vector at the iteration i
K_i – the jacobian matrix for the solution vector
S_y – the noise covariance matrix
R – the regularization matrix

Applying the self-adapting regularization method modifies the solution as follow:

$$x_{i+1} = x_i + \left(K_i^T S_y^{-1} K_i + R_0 + L^T \Lambda L\right)^{-1}\left[\left(K_i^T S_y^{-1}\left(y - f(x_i)\right) + R_0\left(x_a - x_i\right) + L^T \Lambda L\left(x_s - x_i\right)\right)\right]$$

Where
R_0 – (in the case of nadir retrieval) regularization matrix with the weakest possible constraint keeping a meaningful solution
$L^T \Lambda L$ – self adapting regularization term where Λ -profile is determined as the minimizer of the following target function

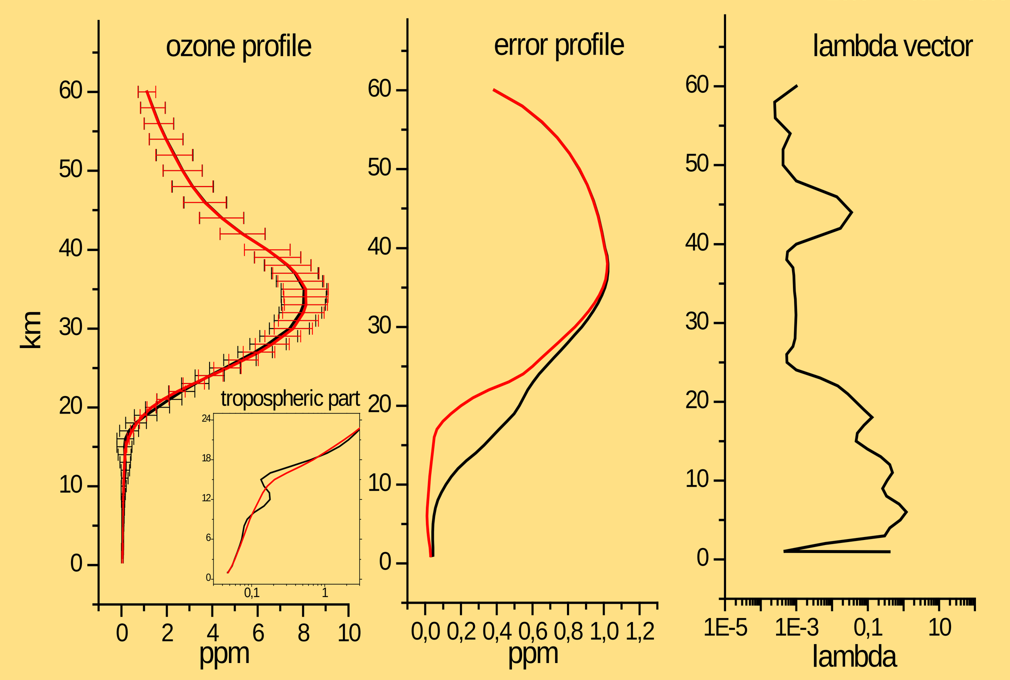
$$\psi_{VS}(\Lambda) = \frac{1}{X_\Lambda}\sqrt{\sum_{j=1}^{n}(S_\Lambda)_{jj}} + \sqrt{\left(\chi^2(X_\Lambda) - \chi^2(X_R) - n w_e^2\right)^+} + \frac{1}{\Delta z}\sqrt{\sum_{j=1}^{n}\left[\left(v_j(X_\Lambda) - w_r \Delta z_j\right)^+\right]^2}$$

The constants w_e and w_r are tunable parameters
w_e - user defined margin for chi-square (related to measurement error)
w_r - user defined vertical resolution limit

5. Application to the retrieval : reduction of oscillating profiles

Ozone profile measured by IASI : 25.06.2008 32.9°E, 40.0°N

Setting parameters Lambda_max, W_e, W_r
10.0 0.1 50.0

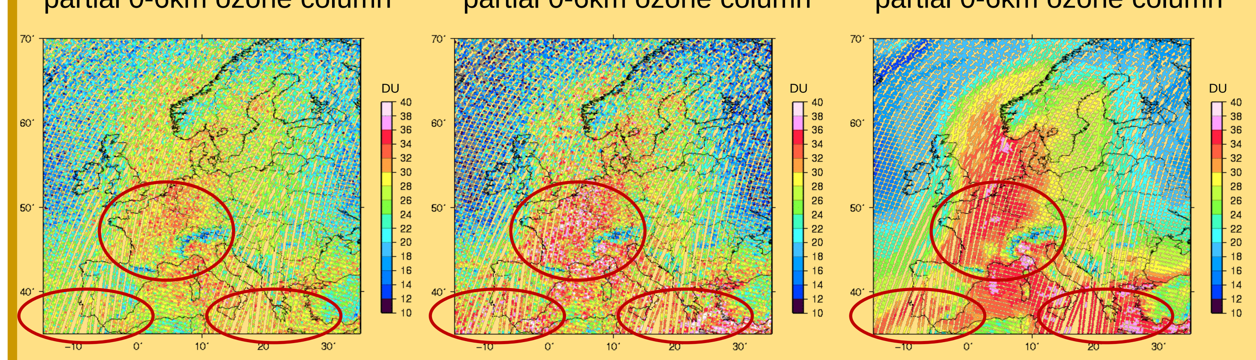


A posteriori self-adapting regularization allows smoothing the retrieved profile where it shows unphysical oscillations due to a lack of information in the measurement. The smoothing is conducted with condition to improve the retrieval error.

6. Simulation Experiment - partial columns maps

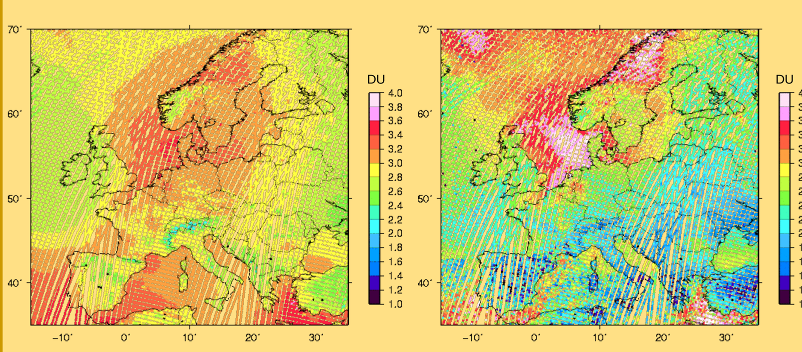
The "IASI like" measurement was simulated based on the chemistry and transport model MOCAGE for a large scale tropospheric ozone pollution event occurring on 20.08.2009.

standard LISA retrieval partial 0-6km ozone column | **self-adapting retrieval** partial 0-6km ozone column | **reference MOCAGE model** partial 0-6km ozone column



Better representation of the pollution plumes

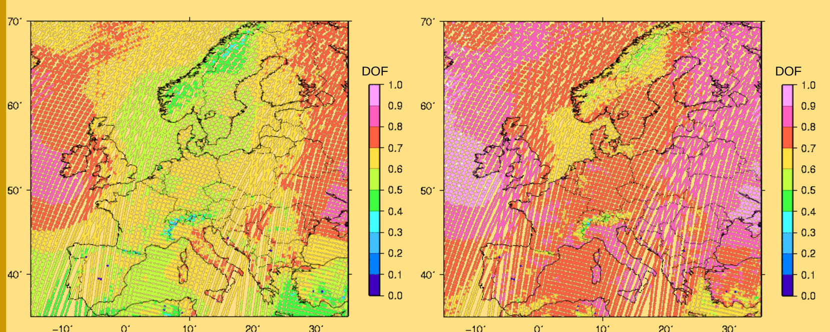
standard LISA retrieval relative retrieval error | **self-adapting retrieval** relative retrieval error



Mean error remains constant for both retrievals (12,3% in relative values)

South-North gradient appears in self-adapting retrieval as the result of optimized error estimation. The error is higher in the northern latitudes due to the lower information in the measurement (less favorable thermal conditions).

standard LISA retrieval degrees of freedom | **self-adapting retrieval** degrees of freedom

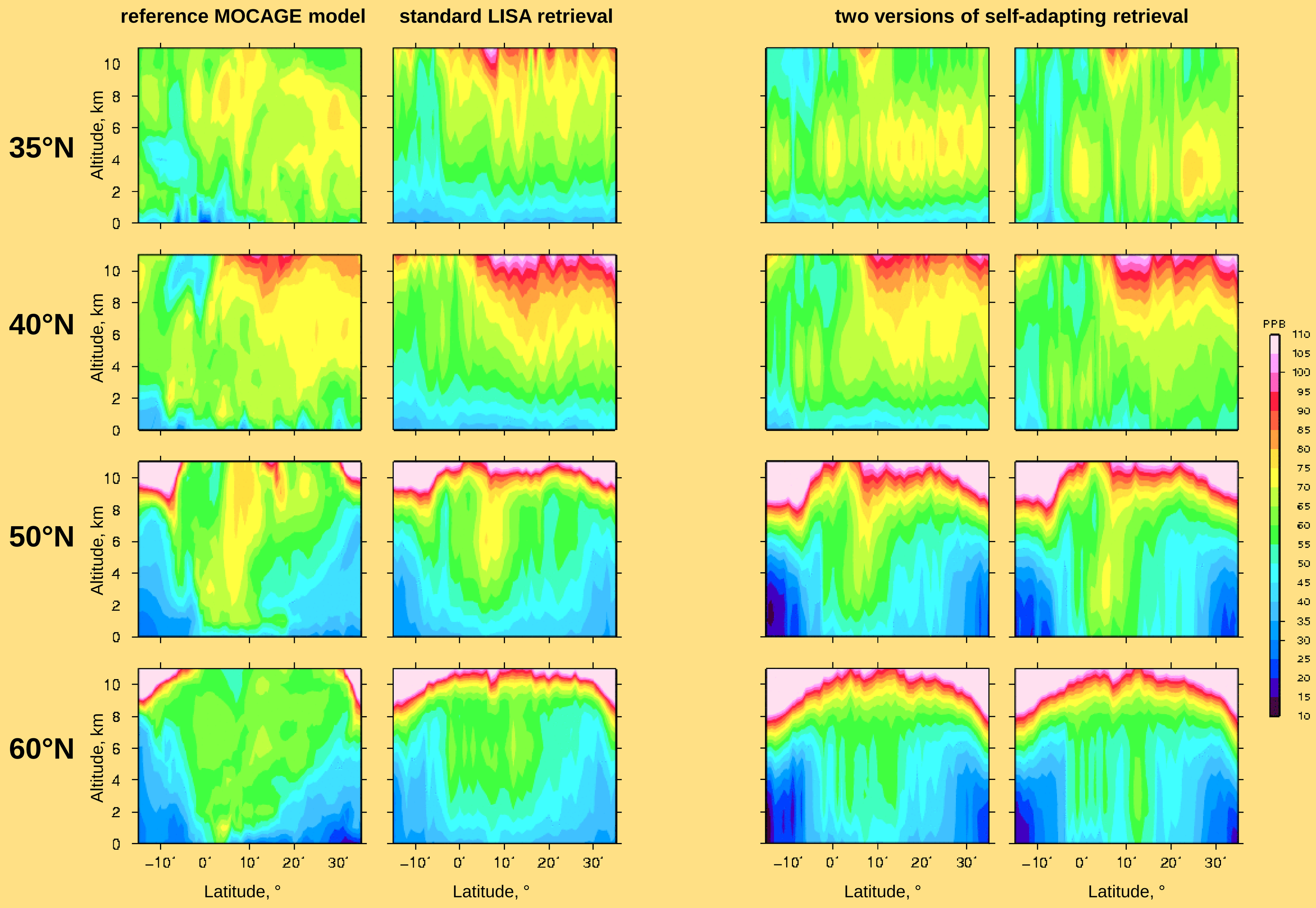


The gain in DOF 0-6km is about 20% :
mean DOF = 0.64 for standard retrieval
mean DOF = 0.78 for the self-adapting.

7. Simulation Experiment - vertical cross-sections

Vertical cross-sections at chosen latitudes are plotted to estimate the impact of the regularization choice on the vertical distribution of the retrieved ozone.

Two versions of the constraint for which we applied the self-adapting method have been used. For latitudes between 40°N and 50°N, the new methodology succeed to better describe the vertical distribution of ozone in the lower troposphere. For latitudes lower than 40°N and higher than 60°N, the method fails to reproduce the vertical distribution of ozone. This is also reflected by the larger errors on the partial columns in these two regions.



Conclusions / Future work

The subject of this study was to apply a self-adapting regularization to the Infrared nadir ozone retrievals . This new method improves the spatial representation of measured ozone structures in the lower troposphere, but the limits of the vertical resolution of the retrieved profile due to the measurement nature do not allow one to retrieve the fine vertical structures in the ozone concentrations.

Preliminary results show that the concentrations close to the surface obtained with the new method may be more strongly dependent on ozone at higher altitudes due to the profile smoothing and do not necessarily represent real surface ozone. The impact of self-adapting regularization on the retrieved profiles should be studied in details. A better constraint has still to be defined.