Satellite remote sensing of SO2 volcanic emission using GOME-2 and IASI data: sensitivity analysis.

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ABSTRACT:
GOME-2 and IASI (both on board of the METOP) have demonstrate to be able to quantify the SO2 amount respectively in the UV and IR spectral region. In case of significant volcanic eruption IASI have enough information content to make possible the retrieval of the vertical profile of the SO2 plume, especially when the plume is ejected above the boundary layer water vapour. GOME-2 can retrieve small SO2 amount (<1DU) also in atmospheric layer close to the surface, like the case of volcanic degassing condition. In this work we intend to combine these two different spectral range in order to have the maximum of information available for a SO2 profile retrieval. We present a sensitivity study using these 2 instruments combined with the optimal estimation (OE) analysis.
We consider different tropospheric and stratospheric scenario, with SO2 loading from 10 to 100 DU, to understand what are the retrieval errors and improved the possibility to retrieve a vertical SO2 profile.

INSTRUMENTS

http://www.esa.int/

METOP

European polar-obiting meterological satellite.
Operational in May 2007
First of tree polar satellite system (EPS) that will cover 14 years
Equator crossing time 9:30 local time

Global Ozone Monitoring Experiment (GOME-2) ESA/EUMETSAT
Scanning spectrometer, 250-790 nm, resolution 0.2-0.4 nm, 960 km or 1920 km swath, resolution 80 x 40 km or 160 x 40 km. Global coverage can be achieved within one day.

Infrared Atmospheric Sounding Interferometer (IASI) CNES/EUMETSAT
Fourier-transform spectrometer, 3.62-15.5 µm in three bands. Four IFOVs of 20 km at nadir in a square 50 x 50 km, step-scanned across track (30 steps), synchronised with AMSU-A. 2000 km swath. Resolution 0.35 cm-1. Radiometric accuracy 0.25-0.58K. Global coverage will be achieved in 12 hours.

OPTIMAL ESTIMATION APPROACH

[C. Rodgers 2000]

FORWARD MODEL $y = F(x,b) + \varepsilon$

y is the measurement vector, x the state vector, F forward model, e measurement error vector

IASI GOME-2 spectra

gas profiles (mixing ratio or density as function of altitude)

radiative transfer codes:
IR range -> RFM (Oxford)
UV range -> SCIATRAN (Bremen)

Forward model => simulations of signal + simulations of variation of the signal (waiting function K)

LINEARISATION

For the purpose of assessing information content and to perform an error analysis it is necessary to linearize the forward model around some reference state vector x_0

$$y - F(x_0) = \frac{\partial F(x)}{\partial x}(x - x_0) + \varepsilon = K(x - x_0) + \varepsilon$$

RETRIEVAL MODEL

State vector x is optimised to minimise the **cost function**:

$$J = (x-x_a)^T S_a^{-1}(x-x_a) + (F(x,b)-y)^T S_e^{-1} F(x,b)$$

This quantifies departure of modeled radiances (based on the state vector) from the observations and the departure of the state from prior knowledge:

Se = measurement covariance matrix
Sa = a priori covariance matrix

Under the linear assumption, the solution state vector which minimises the cost function is

$$\hat{x} = x_a + A(x - x_a) + G_y\varepsilon_y = (I_n - A)x_a + Ax + G_y\varepsilon_y$$

G = gain matrix ~ $\delta x_{retrieval} / \delta y$ $\quad G = \left(K^T S_e K + S_a^{-1}\right)^{-1} K^T S_e^{-1}$

A = averaging kernel ~ $\delta x_{retrieval} / \delta x_{true}$ $\quad A = GK$

Errors in x can be estimated using these matrices e.g.:

$\hat{x} - x = (\mathbf{A} - \mathbf{I}_n)(x - x_a)$	Smoothing error
$+ \mathbf{G}_y \mathbf{K}_b (b - \hat{b})$	Model parameter error:
$+ \mathbf{G}_y \Delta f(x, b, b')$	Forward model error
$+ \mathbf{G}_y \varepsilon$	Error due to noise on measurements

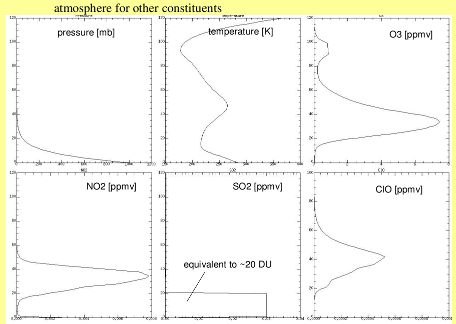
FORWARD MODEL

We use 2 different radiative transfer models in the 2 spectral ranges

UV → SCIATRAN (v2.2) http://www.iup.uni-bremen.de/sciatran/

IR → RFM (v4.28) http://www.atm.ox.ac.uk/RFM/

Both simulations are made with the same gas profiles with SO2 modelled as a box-car profile between 1 and 20km and US std. atmosphere for other constituents



Simulations with 1 km vertical step, gas profile state vector with 1km step

A priori error 100%, gaussian correlation between adiacent level considering 3km of scale height

GOME-2 SNR = 2000 IASI measurements error considered:
0.12 for frequency < 1210 cm-1
0.05 for frequency > 1210 cm-1 [Clarisse 2008]

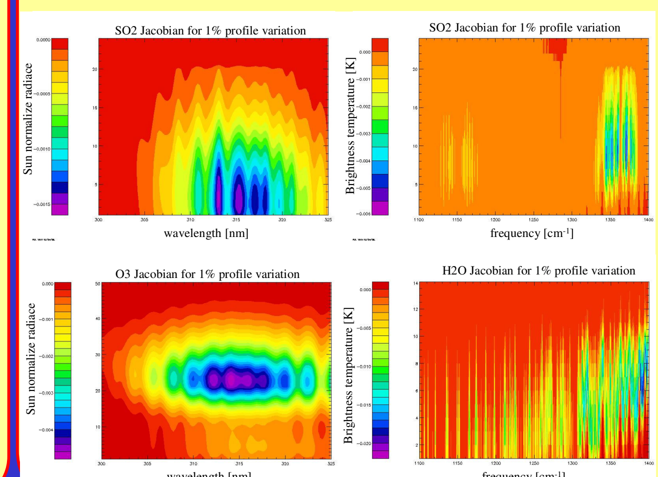
GOME-2 simulations

IASI simulations

These plots are the waiting function (K), in particular the variation of the signal (sun normalize radiance or BT) due to variation of 1% of the vertical profile (ppmv)

Surface reflectance = 0.3

Surface temperature = 285 (same value as the first atm. layer)



ERROR ANALYSIS

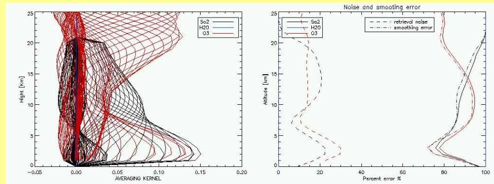
Sx = covariance of the state vector after adding measurements to the a priori → Sqrt(Sx(i,i)) is the total error

Se = G Se G^T → Sqrt(Se(i,i)) is the noise error

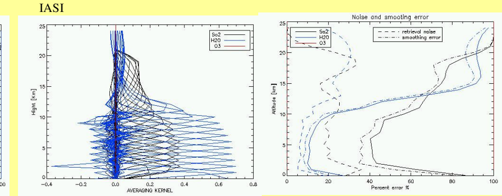
Ss = Sx Sa^{-1} Sx → Sqrt(Ss(i,i)) is the smoothing error

The averaging kernel show the variation of the retrieved state vector as function of the real variation of the atmospheric profile.

GOME-2



IASI



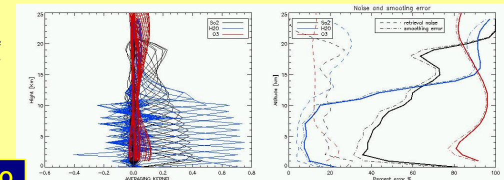
GOME	
DFS for SO2	1.5
DFS for H2O	0.0
DFS for O3	3.8

it is considering only 300-325nm part of the GOME-2 spectra

IASI	
DFS for SO2	4.9
DFS for H2O	8.6
DFS for O3	0.0

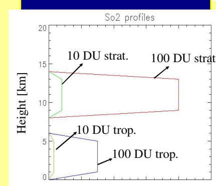
GOME-2 + IASI

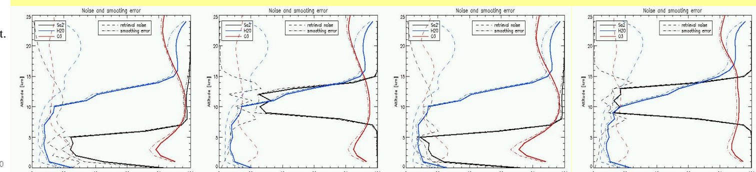
combining the 2 instruments



GOME + IASI	
DFS for SO2	5.6
DFS for H2O	9.3
DFS for O3	3.9

OTHER SCENARIO





INFORMATION CONTENT

The information contend is described by the degrees of freedom of signal (DFS), which is a measure of the number of parameter that can be independently retrieved. It is given by the trace of the averaging kernel.

$$DFS = \sum_{i=1}^{m} \frac{\lambda_i^2}{1 + \lambda_i} = tr(A)$$

Degree of freedom obtained for different scenario

	GOME-2	IASI	GOME-2 + IASI
10DU troposphere	1.0	2.3	2.8
10DU stratosphere	1.1	2.1	2.6
100DU troposphere	1.9	3.2	3.7
100DU stratosphere	1.9	3.1	3.6

Combining the 2 instruments will increase the DFS around 0.5 for any scenario, not particularly affected by the plume height, but more by the amount of SO2

CONCLUSION AND FUTURE WORK

GOME2 is sensitive to the colum amount but not to the vertical distribution of the SO2.
Provided enough SO2 is present, IASI has some vertical information especially in the region where there is a strong temperature gradient.
Adding the GOME-2 spectra to IASI is possible add around 0.5-0.7 of degree of freedom.

FUTURE WORK

Investigate the minimum amount of SO2 detectable in the different scenario. Add a degassing scenario.
Study the possibility to combine the DOAS GOME-2 slant SO2 amount with IASI and optimal estimation retrieval.

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