SO₂ column and plume height retrieval from direct fitting of GOME-2 backscattered radiance measurements

Introduction
The use of satellite measurements for SO₂ monitoring has become an important aspect in the support of aviation control. Satellite measurements are the only information available on SO₂ concentrations from volcanic eruption events and enhanced SO₂ may indicate the presence of ash. Satellite instruments also provide information on SO₂ pollution sources. SO₂ columns have been derived from several UV nadir sensors (GOME, SCIAMACHY, GOME-2) with traditional DOAS methods. However, both SO₂ and O₃ strongly absorb in the UV range of 310-220 nm (Figure 1); this limits the accuracy of the DOAS technique, which is valid for optically thin media only. We therefore present an enhanced technique for the simultaneous retrieval of total vertical columns of O₃ and SO₂ from satellite measurements. The method involves direct fitting of simulated Earthshine radiances to the measured radiance spectrum. In the process, the use of parameterized vertical SO₂ profiles allows for the derivation of the peak height of the SO₂ plume, along with the total column amounts.

Background physics
The way different layers of the atmosphere contribute to the top-of-atmosphere radiance spectrum J(λ), can be visualized by means of the vertical profile of the local mass factor and its gradient (Figure 2). The respective quantities are Jacobians with respect to total gas column and plume height. Yang et al. (2010) showed and explained the differences between these two weighting functions in words: changing the SO₂ concentration in an atmospheric layer has a different effect on J(λ) than changing the altitude of this layer. This phenomenon allows for the derivation of both total column and height information of an SO₂ plume.

Method
We derive SO₂ total vertical column density and effective SO₂ plume height by means of the direct fitting retrieval algorithm GODFIT (1). This iterative scheme performs forward radiation and Jacobian calculations with the LIDORT radiative transfer model and contains an optimal estimation inversion scheme. In the model atmosphere, volcanic SO₂ plumes are parameterized in a similar fashion as described in Yang et al. (2010, [3]).

Below we show results from retrievals of SO₂ vertical column density (VCD) and effective plume height. For the closed-loop retrievals (Figure 4) the state vector was composed of the VCD of O₃ and SO₂, the SO₂ plume height and a surface albedo. No clouds or aerosol were included. For the retrievals from GOME-2 observations (Figures 5, 6), a second order surface albedo closure polynomial was used as well as a Ring-spectrum scale factor. Here, clouds were treated as Lambertian reflectors and with use of the independent pixel approximation.

Results
Before we show results from retrievals of SO₂ vertical column density (VCD) and effective plume height. For the closed-loop retrievals (Figure 4) the state vector was composed of the VCD of O₃ and SO₂, the SO₂ plume height and a surface albedo. No clouds or aerosol were included. For the retrievals from GOME-2 observations (Figures 5, 6), a second order surface albedo closure polynomial was used as well as a Ring-spectrum scale factor. Here, clouds were treated as Lambertian reflectors and with use of the independent pixel approximation.

Closed-loop retrievals
Figure 4 shows results from retrievals on synthetic spectra (closed-loop retrievals) for different ‘true’ vertical SO₂ and SO₂ plumes, along with the total column amounts. Line style indicates solar zenith angle. All results are for a Lambertian surface albedo of 0.04.

Kasatochi 8 August 2008
The high SO₂ concentrations emitted in the 2008 eruption from this Aleutian volcano were clearly observed by the METOP-I/GOME-2 instrument. Simultaneous retrieval results of SO₂ total column and plume height are depicted in Figure 5. Comparison with CALIPSO-CALIOP data of the eruption’s ash cloud (not shown) indicates that our height estimates are accurate within about 2 km. In particular, at the edges of the emission, SO₂ concentrations in the GOME-2 pixels may be underestimated, leading to a possible underestimation of the plume height (‘Edge effect’, Yang et al. (2010) [3]). Near the edges of the SO₂ cloud, derived peak height values are therefore lower.

Eyjafjall 9 May 2010
The GOME-2 instrument proved capable of monitoring this year’s eruption for many days in a row. Deriving plume height here is more challenging, as SO₂ emission concentrations varied greatly over time and where dragged along with pressure systems in the atmosphere (Figure 6). As a result, the ‘edge effect’ is expected to play an important role in the derivation of SO₂ height information from Eyjafjall measurements. When following this reasoning, the higher peak height values in Figure 6 may be the most trustworthy.

References

Contact
Jeroen.vanGent@aeronomie.be

Jeroen van Gent (1), Robert Spurr (2), Nicolas Theys (1), Michel Van Roozendael (1), Meike Rix (3), Pieter Valks (3)

(1) Belgian Institute for Space Aeronomy, 3 Avenue Circulaire, B-1180 Brussels, Belgium
(2) RT-Solutions, Inc., 9 Channing Street, Cambridge, MA 02138, United States
(3) German Aerospace Center, PO Box 1116, D-82234 Wessling, Germany