Algorithms/Results (SO$_2$ and ash) based on SCIAMACHY and GOME-2 measurements

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- Contents -

- Support to Aviation Control Service (SACS)
- Example of results for the eruption of the Eyjafjallajokull volcano
- Algorithmic developments

Ash plume from the Eyjafjallajokull eruption on 15 Apr. 2010 © Saeberg/Reuters
The Support to Aviation Control Service (SACS) intends to deliver in near-real time data from space-based instruments regarding SO₂ and aerosol (ash) data possibly related to volcanic activity. In case of an event notifications are send by email to users pointing them to a dedicated webpage with detailed information. If possible information on the location, elevation and motion of volcanic plumes will also be provided in collaboration with the SAVAA project.

Notifications of events and data from SACS+ can be useful to the VAACs and other interested users: volcanic observatories, air quality monitoring institutes, scientist, etc.

Currently: 66 subscribers
Volcanic SO$_2$ services

**DLR: GOME-2**

**IUP Bremen: GOME-2**

**ULB: IASI**

SAVAA GOME-2 SO2 alert service:
http://www.doas-bremen.de/gome2_so2_alert.htm
Partners in SACS

Belgian Institute for Space Aeronomy (BIRA-IASB) leader
N. Theys, H. Brenot, J. van Gent and M. Van Roozendael

Royal Netherlands Meteorological Institute (KNMI)
R. van der A and Roeland van Oss

Free University of Brussels (ULB)
P. Coheur, L. Clarisse and C. Clerbaux

German Aerospace Center (DLR): data provider
P. Valks, M. Rix, D. Loyola
Data products of SACS

Near-real time and archive service

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Data type</th>
<th>Participants</th>
<th>Data products</th>
<th>Availability</th>
<th>Alerts</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIAMACHY</td>
<td>UV/visible</td>
<td>BIRA, KNMI</td>
<td>SO$_2$ columns absorbing aerosol index</td>
<td>+</td>
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<td>(ENVISAT)</td>
<td></td>
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<td>GOME-2</td>
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<td>DLR, KNMI</td>
<td>SO$_2$ columns* absorbing aerosol index</td>
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<tr>
<td>(MetOp-A)</td>
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<td></td>
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</tr>
<tr>
<td>OMI</td>
<td>UV/visible</td>
<td>KNMI</td>
<td>SO$_2$ columns absorbing aerosol index</td>
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<td>[+]</td>
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<tr>
<td>(Aura)</td>
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<tr>
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<td>Infrared</td>
<td>ULB</td>
<td>SO$_2$ index and columns ash indicator</td>
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<tr>
<td>(MetOp-A)</td>
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+ = currently available        [+]= to come during SACS+

*   Operational product from DLR.
**  IASI alerts currently available via ULB.

[ All four sensors are nadir viewing instruments on near-polar sun-synchronous orbits]
Alert system: subscription to e-mail list

SO2 data and alert service

Subscription to the notification system

The following form allows you to subscribe to the automatic e-mail notification of exceptional SO2 concentrations presented on these web pages. This service and the data behind it is provided free-of-charge. The notifications are sent to the e-mail address you provide.

All fields marked * are required. Links marked 'help info' provide information on the choices (opens a new window).

You will be contacted through the e-mail address you provide in the form when you have been added to the service, this may take a few days. The information you supply will be treated confidentially and your e-mail address will not be given to anyone else.

Name: 
Organisation: 
Country: 
E-mail address: 

Region(s) of interest:
- Europe & Africa
- Asia & Australia
- North & South America
- North & South Pacific

Please give a (short) description why you would like to be added to the e-mail notification service. The reason to ask this is that we -- that is the service team and the financiers of the service -- would like to know who is using the service and the data and for what purpose. (Note that HTML coding is not allowed here.)
Alert system

Eruption of the Vanuatu

Criteria for exceptional SO2 events

For each pixel with SO$_2$ SCD>3 DU, the 8 surrounding pixels are evaluated:

- SO$_2$ SCD>3 DU: + 1 point
- SO$_2$ SCD<0 DU: -1 point

If $\sum$ points $\geq$ 5 then an alert is triggered and an e-mail is sent to interested users.

SACS notification of exceptional SO2 concentration

Process date: 2005 05 15
Process time: 23:56:01 CET
Instrument: SCIAMACHY
No. notices: 1
Alert notice: 1

http://sacs.aeronomie.be/alert/?alert=20050515_224502_001

Start date: 2005 05 15
Start time: 22:45:02.724 UTC
Aver. long.: 167.7 deg.
Aver. latit.: -16.9 deg.
Aver. sza: 24.5 deg.
Max. SO2 vcd: 41.3 DU
Remark:
Ongoing development: multi-sensors approach

**Aim:** improve global alerts by using polar orbiting nadir sensors

- **SO2 vertical column [DU]**
  - 18 June 2009
  - SCIAMACHY - BIH-IASB-DRU-ESA
  - GOME-2 - BIH-IASB-DRU
  - OMI - KNMI-BIH-IASB-NASA

- **IASI SO2 20090618am**
  - IASI SO2 20090618pm
SCIAMACHY is the worst instrument for an alert system (global coverage achieved in 6 days)

Using data from satellite instruments with different overpass times is relevant to reduce the $\Delta t$ between the time of the eruption and the time when the alert is sent.

 Possibility to associate a level of confidence to an event if it is observed by several sensors. However, a high level of confidence is at the expense of a small $\Delta t$!

The synergistic use of GOME-2 and IASI data (both on MetOp-A) enables to discriminate surface $SO_2$ from FT/stratospheric $SO_2$. 

Multi-sensors approach
The eruption of the volcano Eyjafjallajokull

- The eruption started on 14th of April with little SO$_2$ detected (maybe obscured by the ash cloud).

- After the 23rd of April, the evolution of the eruption has lead to a much stronger signal coming from SO$_2$.
The eruption of the volcano Eyjafjallajokull

Combined SCIAMACHY and GOME-2 SO$_2$ images

Period: 23/04 – 17/05, 2010

SACS has generated more than 50 alerts for this period
The eruption of the volcano Eyjafjallajokull

GOME-2 monitoring of SO$_2$ plume

- Main area affected to the south and west
- Main SO$_2$ emissions in 2$^{nd}$ phase of eruption
- Largest individual values and largest total mass not at the same time
Absorbing aerosol index (AAI) is calculated based on the measured reflectances at 340 and 380 nm and indicates for the presence of elevated absorbing aerosols (volcanic ash but also desert dust and biomass burning).

\[
AI_\lambda = -100 \cdot \left\{ \log_{10} \left( \frac{I_\lambda}{I_{\lambda 0}} \right)_{\text{meas}} - \log_{10} \left( \frac{I_\lambda}{I_{\lambda 0}} \right)_{\text{Ray}} \right\}
\]

- SCIAMACHY AAI data available on SACS website (GOME-2 available soon).
- SCIAMACHY and GOME-2 AAI products are produced by KNMI

=> more in P. Stammes’s talk
SCIAMACHY and GOME-2 SO$_2$ VCD retrieval – starting point:

DOAS approach (three steps)

1. **SO$_2$ slant columns** (integrated concentration along the mean optical light path) are retrieved from satellite measurements with a **DOAS** technique in the range 315 – 326 nm.

DOAS fits a calculated spectrum – which is based on the cross sections of SO$_2$, ozone and Ring effect and on a reference spectrum – against the measured spectrum.
Algorithmic developments

2. **Background correction** for the offset due to the reference spectrum and the anticorrelation between \( \text{SO}_2 \) and \( \text{O}_3 \) observed at high solar zenith angles (high latitudes), due to strong ozone interferences.

3. **\( \text{SO}_2 \) vertical columns** are calculated by applying an “air mass factor” to account for the light path enhancement w.r.t. to the vertical path.

\[
\text{VCD} = \frac{\text{SCD}}{\text{AMF}}
\]

**AMFs look-up-tables** (calculated using Lidort RTM) with a set of entries (SZA, Viewing geometry, albedo, cloud fraction and cloud top pressure) and for **3 different plumes heights** (boundary layer, free-troposphere and stratospheric conditions).
Algorithmic developments

Alternative approach: iterative volcanic SO$_2$ retrieval (IUP Bremen)

Problem:
- For large volcanic eruptions, the relation between absorption signal and SO$_2$ column becomes non-linear

Solution:
- Iterative procedure

Results:
- Improved retrievals
- Larger SO$_2$ columns
- Change in SO$_2$ spatial pattern

=> significant improvement!
Algorithmic developments

Alternative approach: direct fitting (BIRA-IASB)

Tool
GODFIT is a **direct fitting** algorithm that includes LIDORT as forward radiative transfer model and a ‘state-of-the-art’ Rotational Raman Scattering (RRS) code.

Inversion techniques in development
- volcanic ash/aerosol retrieval → based on the different light intensity and RRS response of absorbing/non absorbing aerosols (LIDORT-RRS is the baseline forward RT code in GODFIT)
- improvement of the SO2 VCD retrieval (high SO2 signal)
- retrieval of the peak altitude of the SO$_2$ plume (particularly interesting for the VAACs).
Preliminary results: tests on synthetic UV spectra (310-320 nm) generated by LIDORT for a predefined standard atmosphere with the contribution from R. Spurr (RT Solutions, Inc.)

**SO₂**
- **0.5 DU**: 3.2 km (retrieved)
- **1.5 DU**: 5.58 km (retrieved)
- **15 DU**: 5.5 km (retrieved)

*Height: 2.5 km (truth)*

*Height: 5.5 km (truth)*

*Height: 5.5 km (truth)*

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**SO₂ plume height retrieval**